Measuring Urban Form/Street Space and the Effect on Emissions in China

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China Sustainable Transportation Center

Global Platform for Sustainable Cities (GPSC) *Expert Meeting*

Measuring the Impact of Urban Planning Strategies on GHG Emission*S*

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The World Bank, Washington D.C., USA

Outline

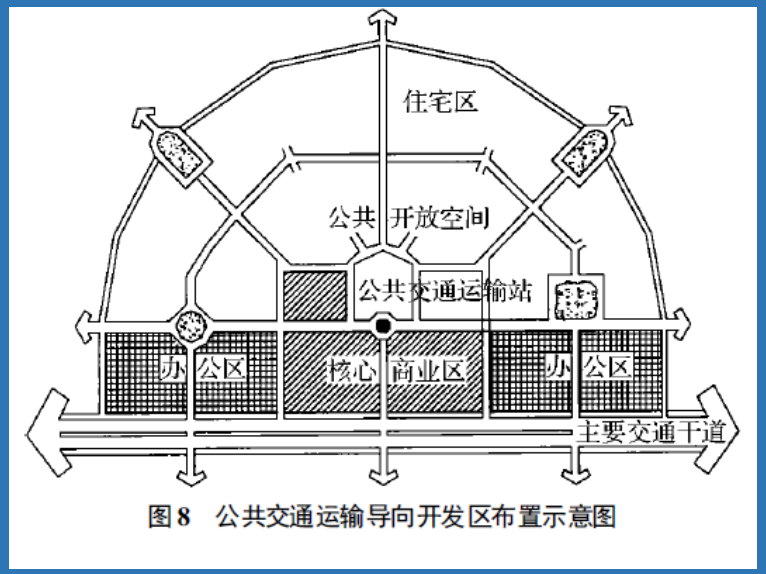
1. Measuring TOD
2. Measuring Street Space
3. Modelling CO2 Emissions in Jinan, China
4. Conclusion and Discussion

Measuring TOD in China

1

Transit Oriented Development

A concept first raised by Peter Calthorpe in the 1990s, in general refers to an urban environment with high densities, mixed land uses, and quality public space within easy walking distance of a transit stop.



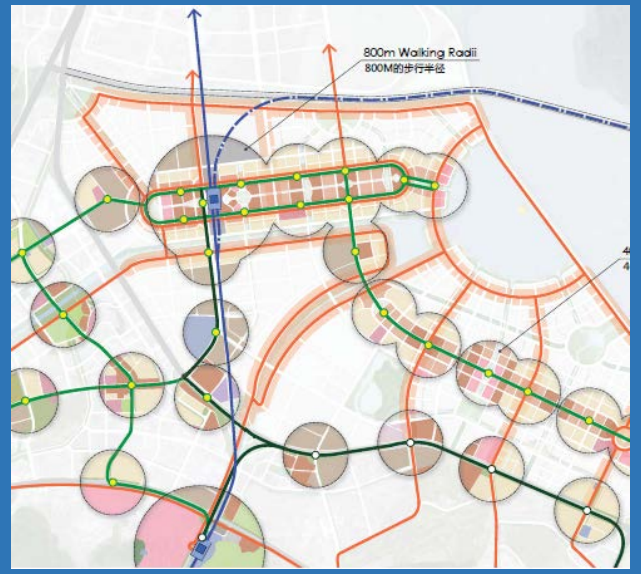
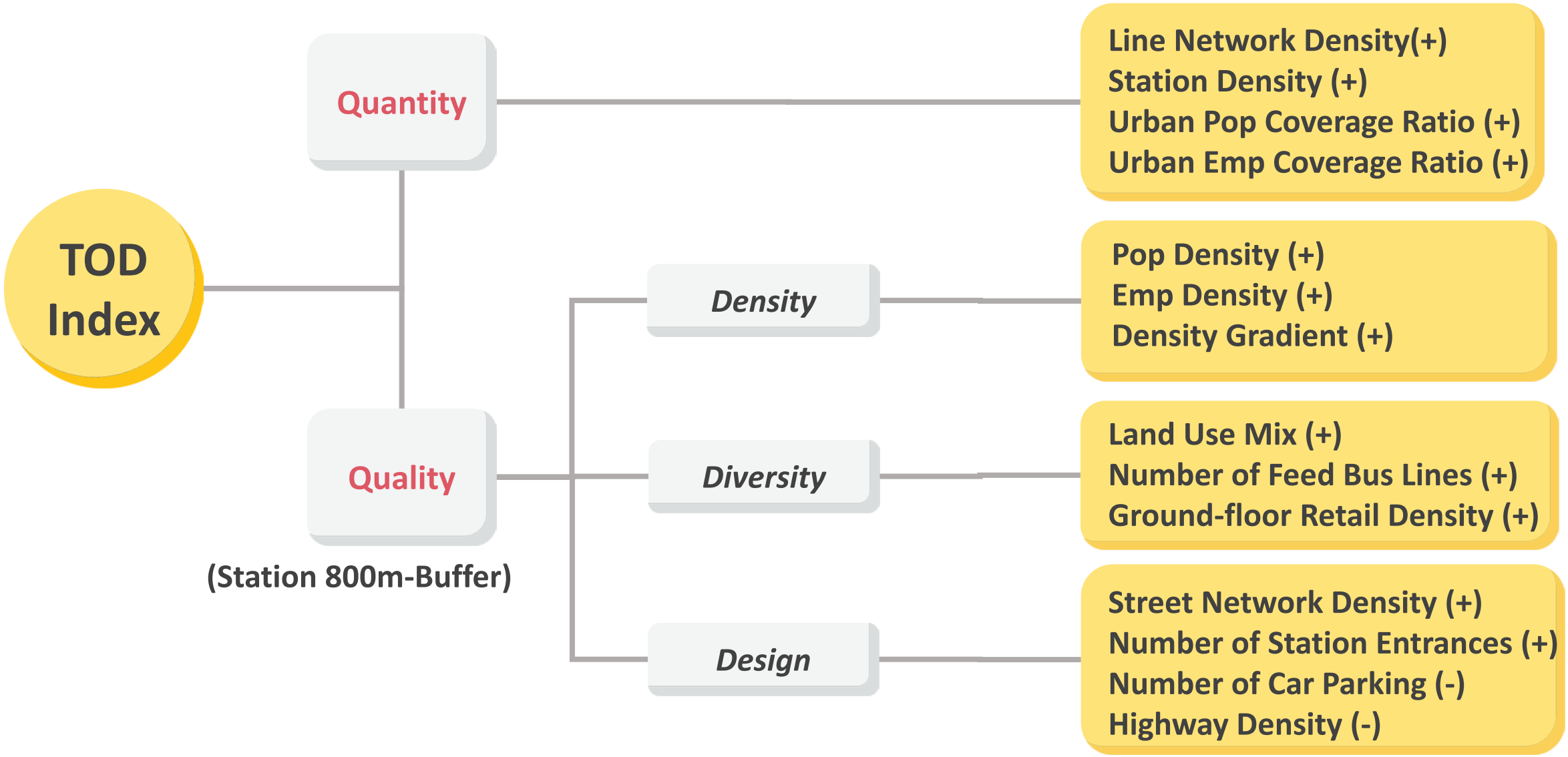


Photo: Christian Bruce

TOD Measuring Framework



TOD Quality indicators - Density

① Population Density

Population density within 800m buffers

② Employment Density

Employment positions within 800m buffers

③ Density Gradient

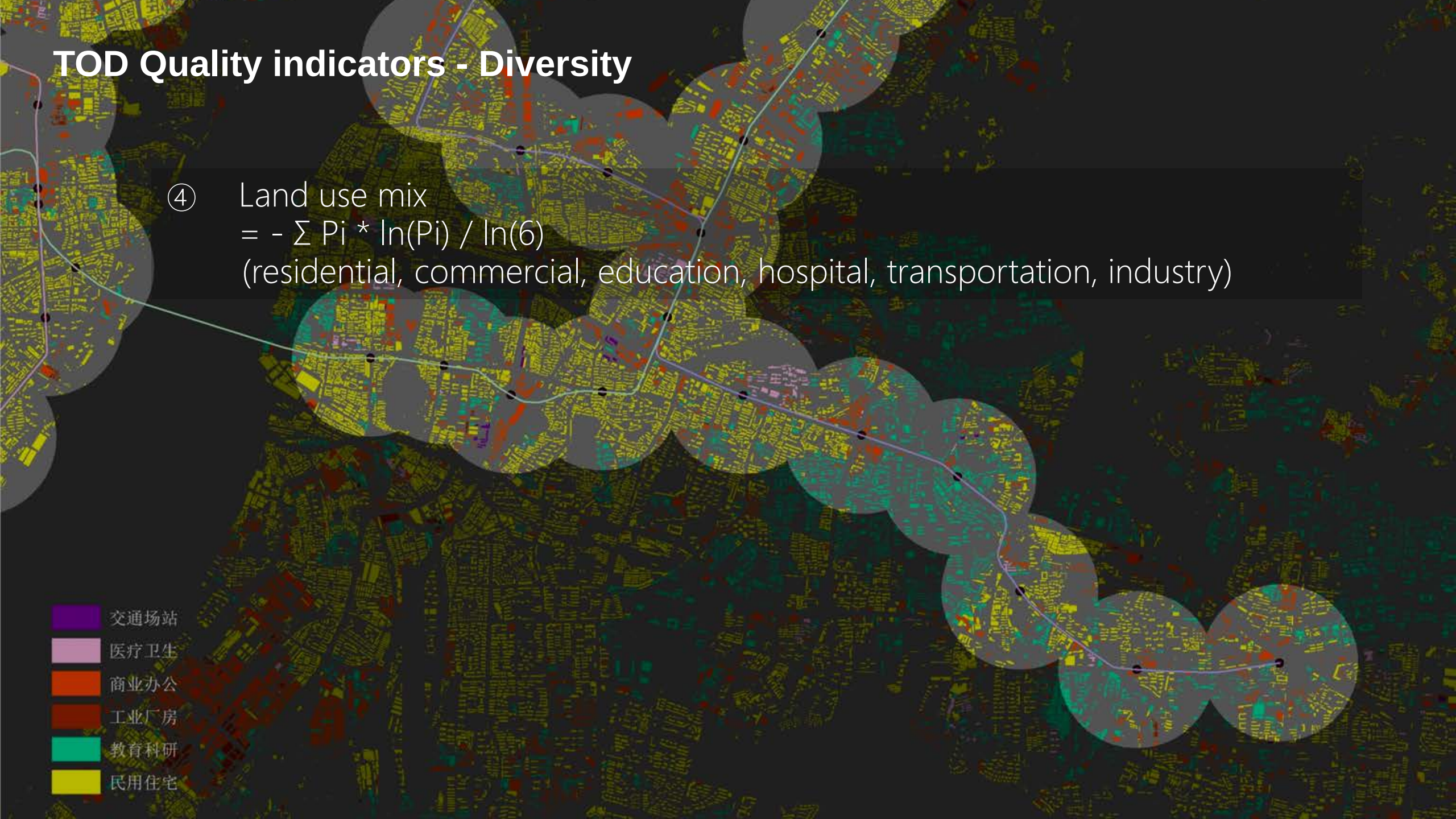
FAR within 400m to stations /FAR within 400m-800m to stations

TOD Quality indicators - Diversity

④ Land use mix

$= - \sum P_i * \ln(P_i) / \ln(6)$

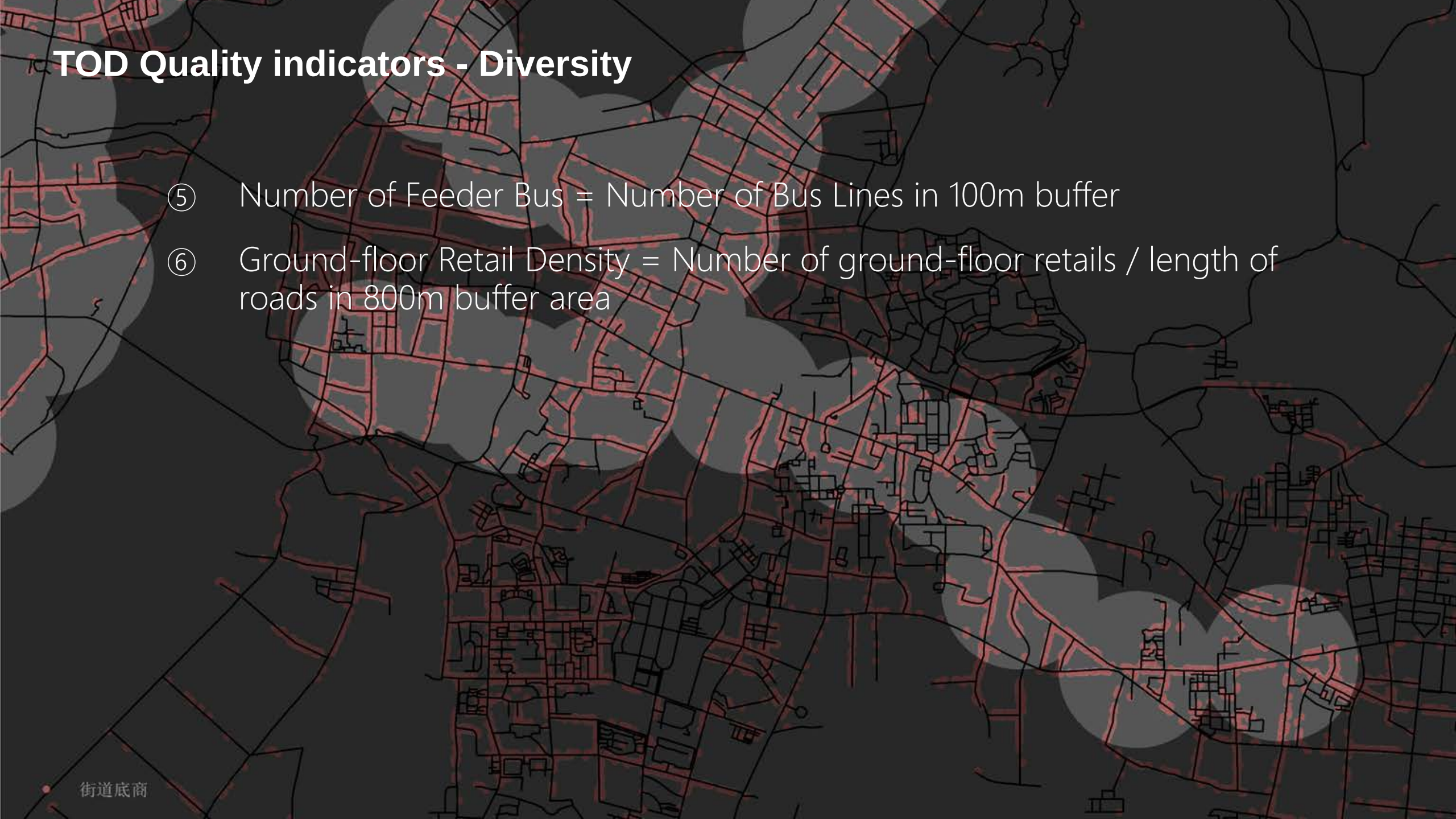
(residential, commercial, education, hospital, transportation, industry)



TOD Quality indicators - Diversity

⑤ Number of Feeder Bus = Number of Bus Lines in 100m buffer

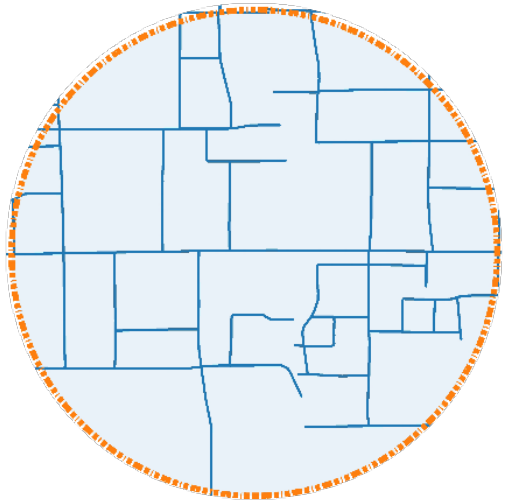
⑥ Ground-floor Retail Density = Number of ground-floor retails / length of roads in 800m buffer area



TOD Quality indicators - Design

⑦ Street Network Density

All roads (except highways and expressways) length (km)/800m buffer area (km2)

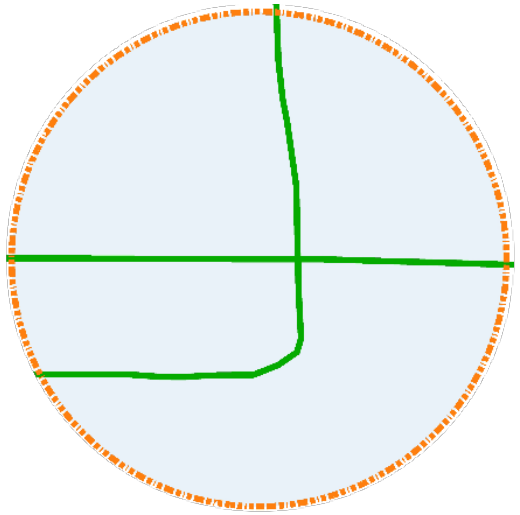


Network Density

All Roads Except Highway & Expressway

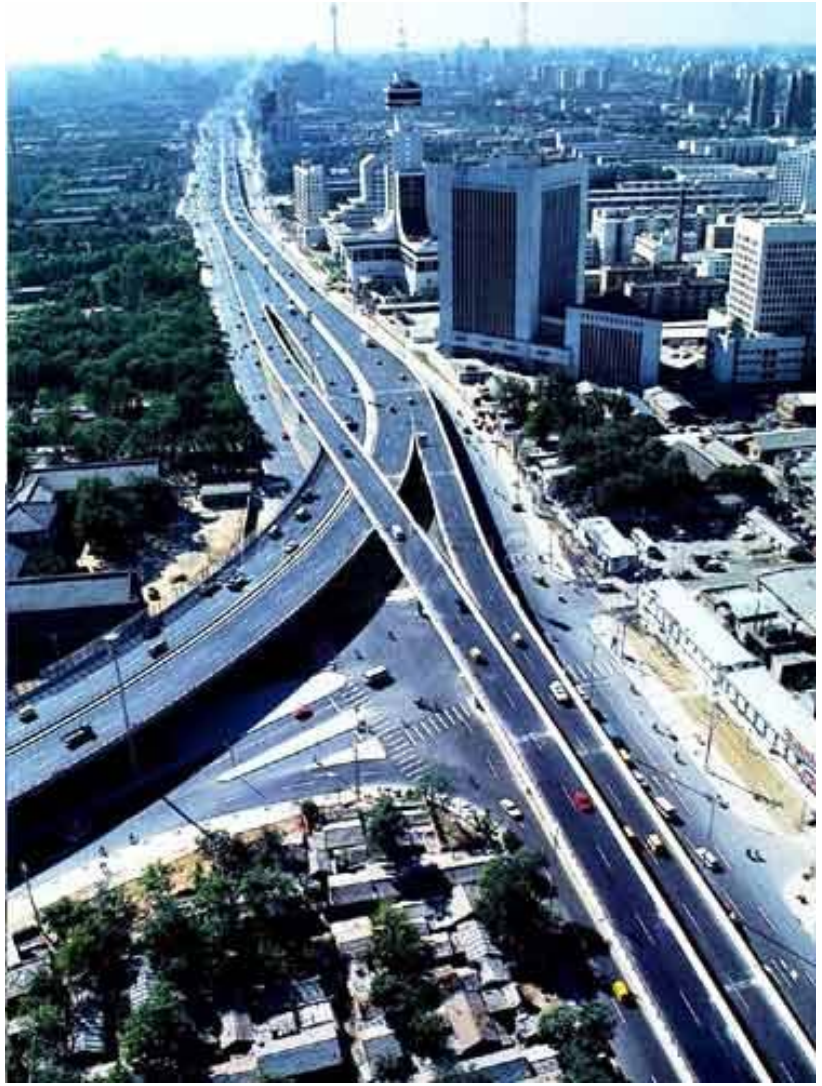
⑧ Highway Density

Length of expressways (km)/800m buffer area (km2)



Expressway Density

Highways and Expressways

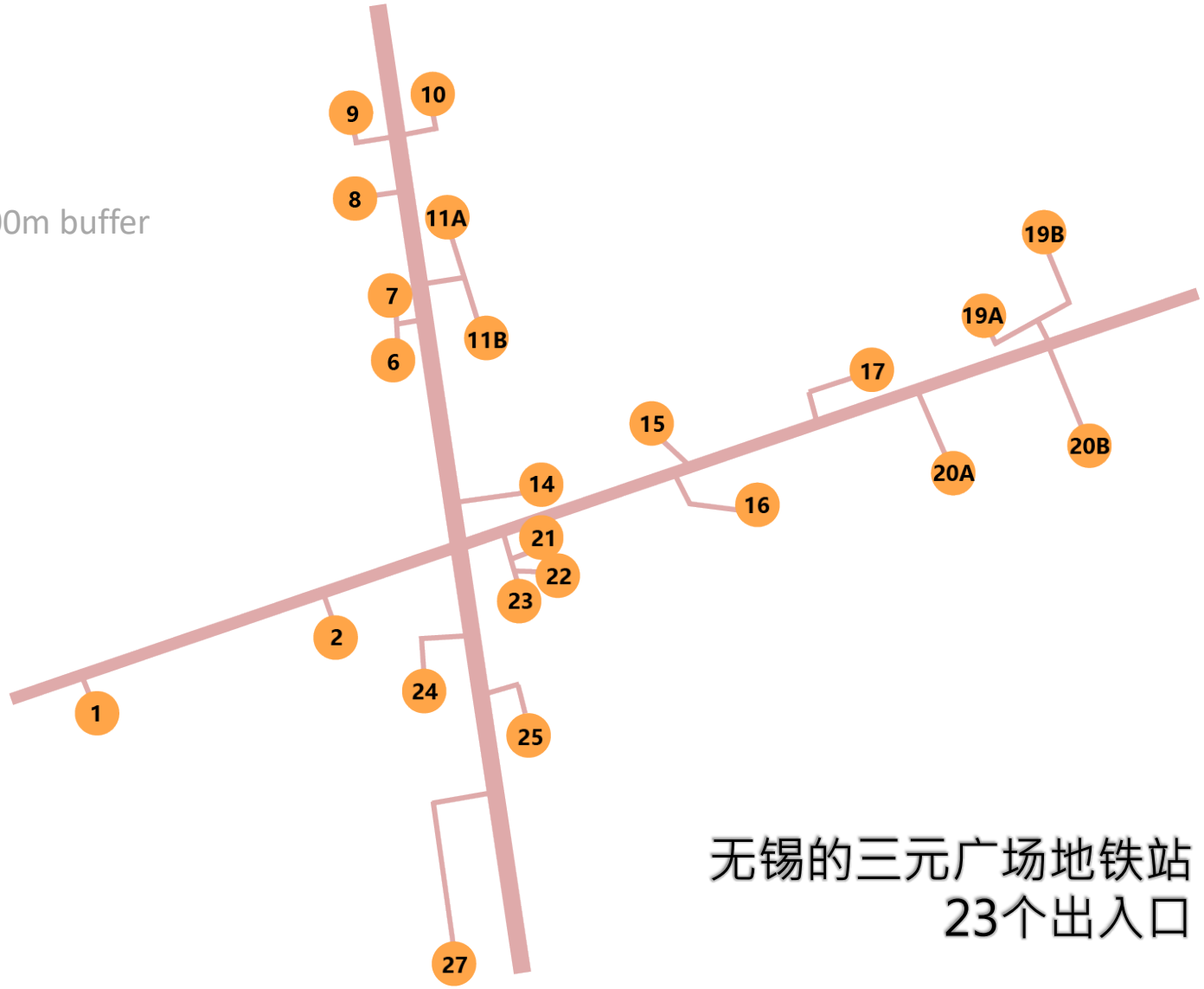


TOD Quality indicators - Design

⑨ Number of Station Entrance

⑩ Number of Car Parking

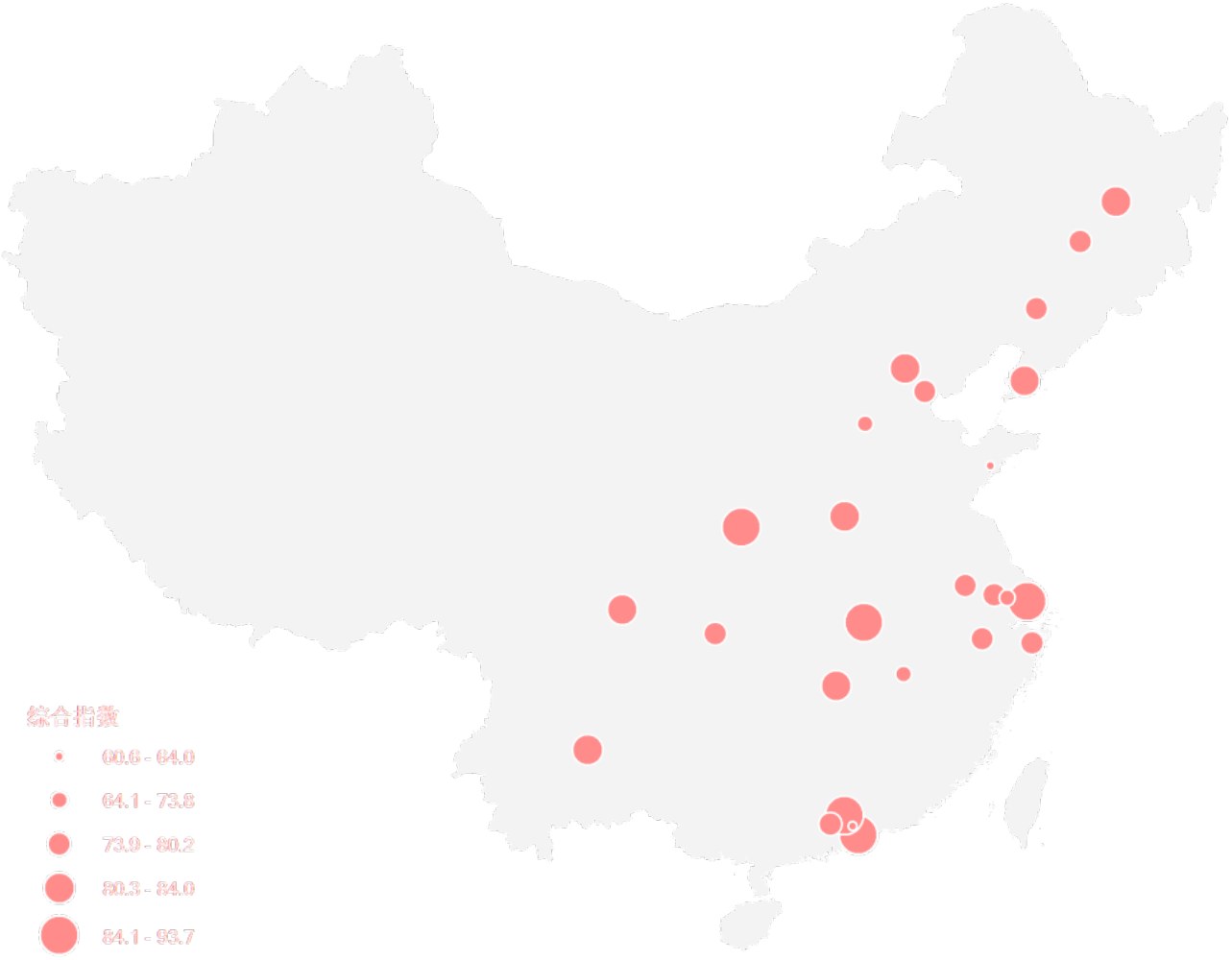
= Number of Public Parking POIs within 200m buffer

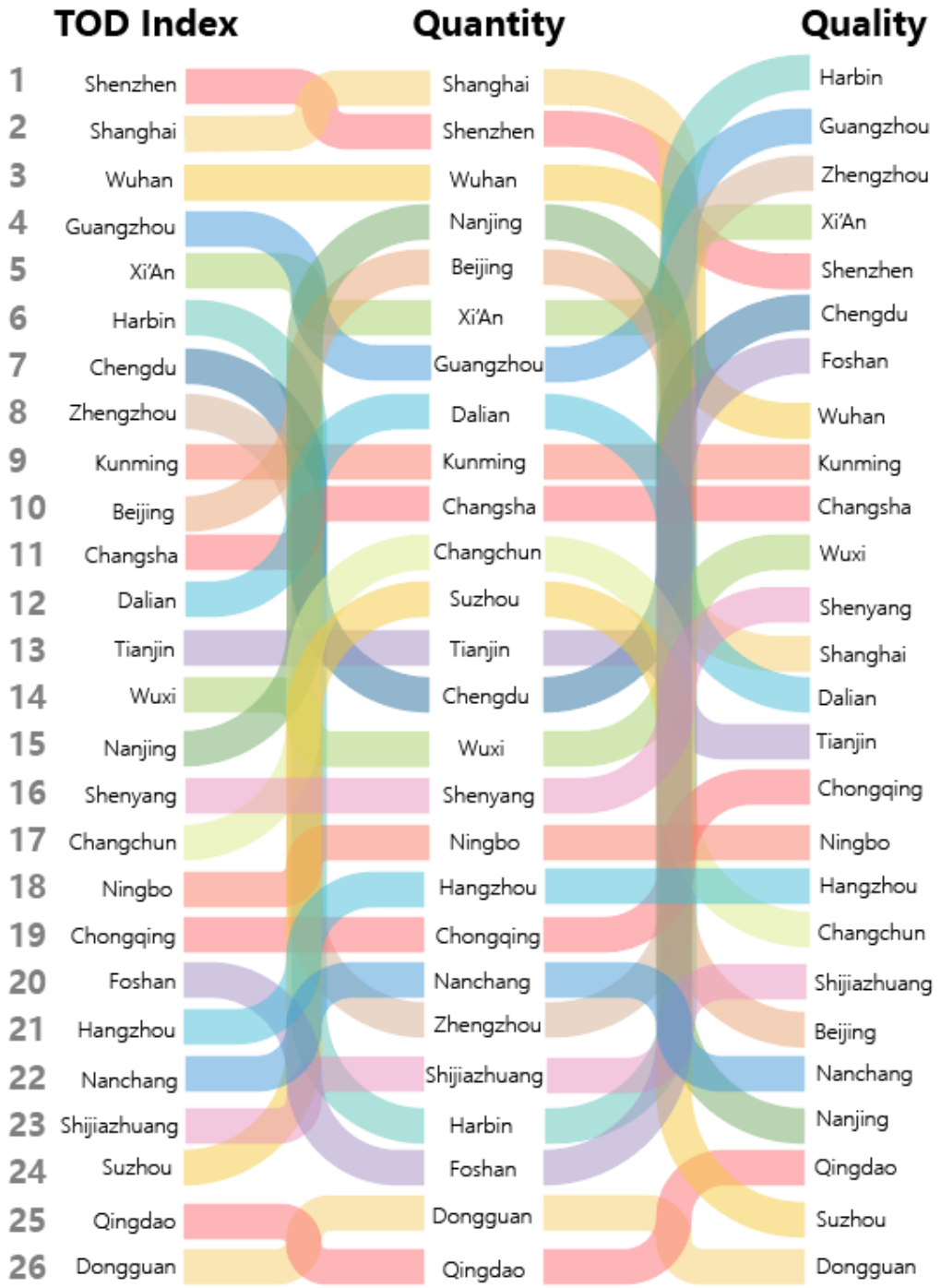


无锡的三元广场地铁站
23个出入口

TOD Index Calculation- Indicator Weighting

TOD Index Ranking





TOD and Air Quality: A City-level Examination

China is facing severe air quality threats due to various factors, among which transportation, traffic congestion and increasing dependence on private vehicles are becoming ever more critical.

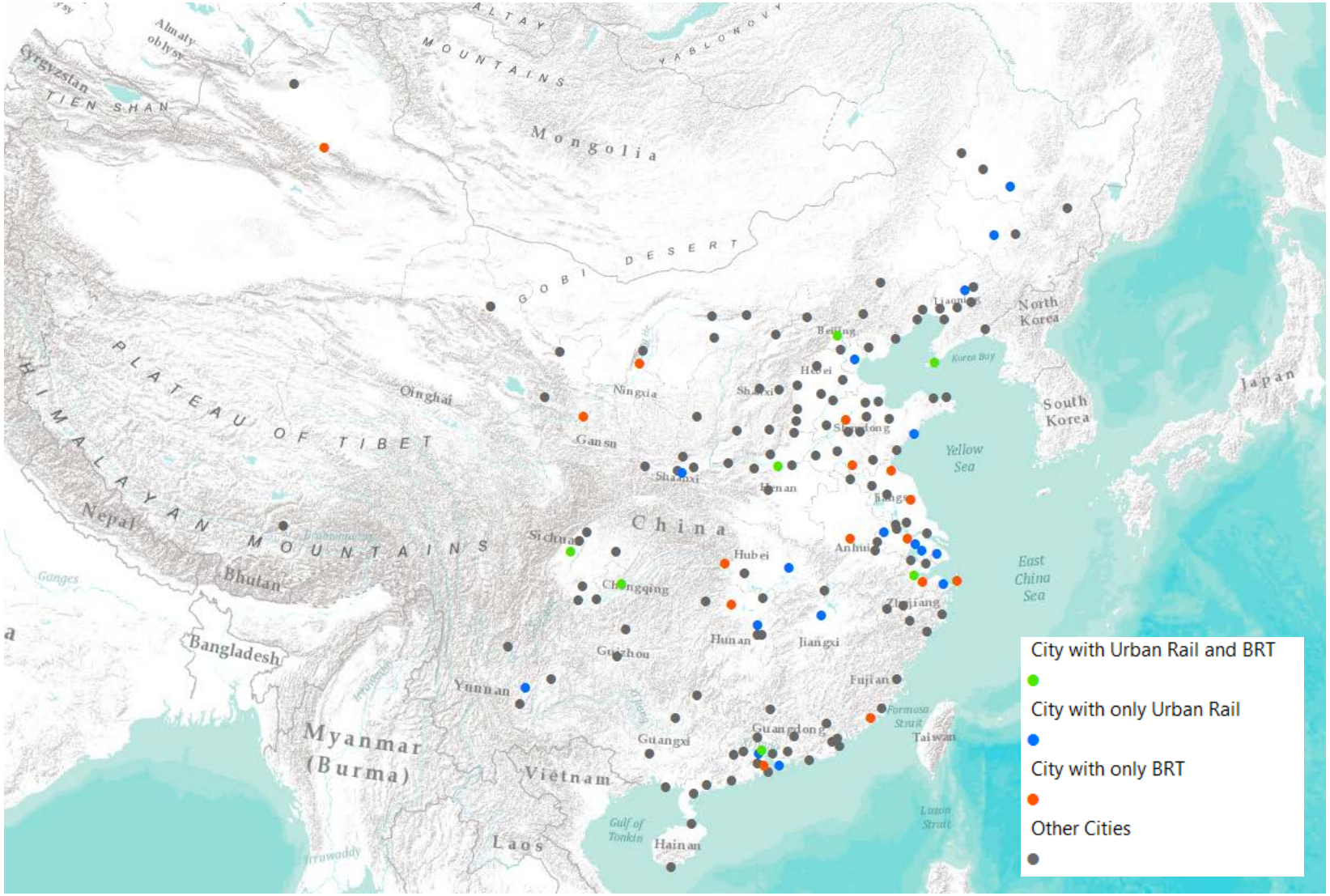
Transit-oriented development (i.e., TOD) has often been claimed as an effective solution to promote more sustainable travel among urban residents and to shape clean cities. However, no research explicitly links air quality and TOD patterns with empirical evidence in rapidly urbanizing China.

Smog and Traffic Jam in Beijing

Research Question

Is a city with a higher degree of TOD in China associated with better air quality after controlling for other confounding factors?

Air Quality Data



152 China cities with AQI record

Daily Air Quality Index were collected for 152 China major cities over year 2014 from China MEP website:

37 cities with either urban rail or bus-rapid-transit (BRT) system, among which
7 cities with both systems
17 cities with only urban rail system
15 cities with only BRT system

115 cities with no urban rail or BRT system

Spatial Error Model Result

1) **Urban Rail TOD index is significantly and negatively correlated with Year , Spring and Fall AQI;**
2) BRT TOD index appears to have no significant relationship with air quality;
3) Impacts of energy use, urban green and road network are consistent with the literature;
4) Daily precipitation plays an important role in AQIs (except Fall AQI)

Table 9
Spatial error model result.

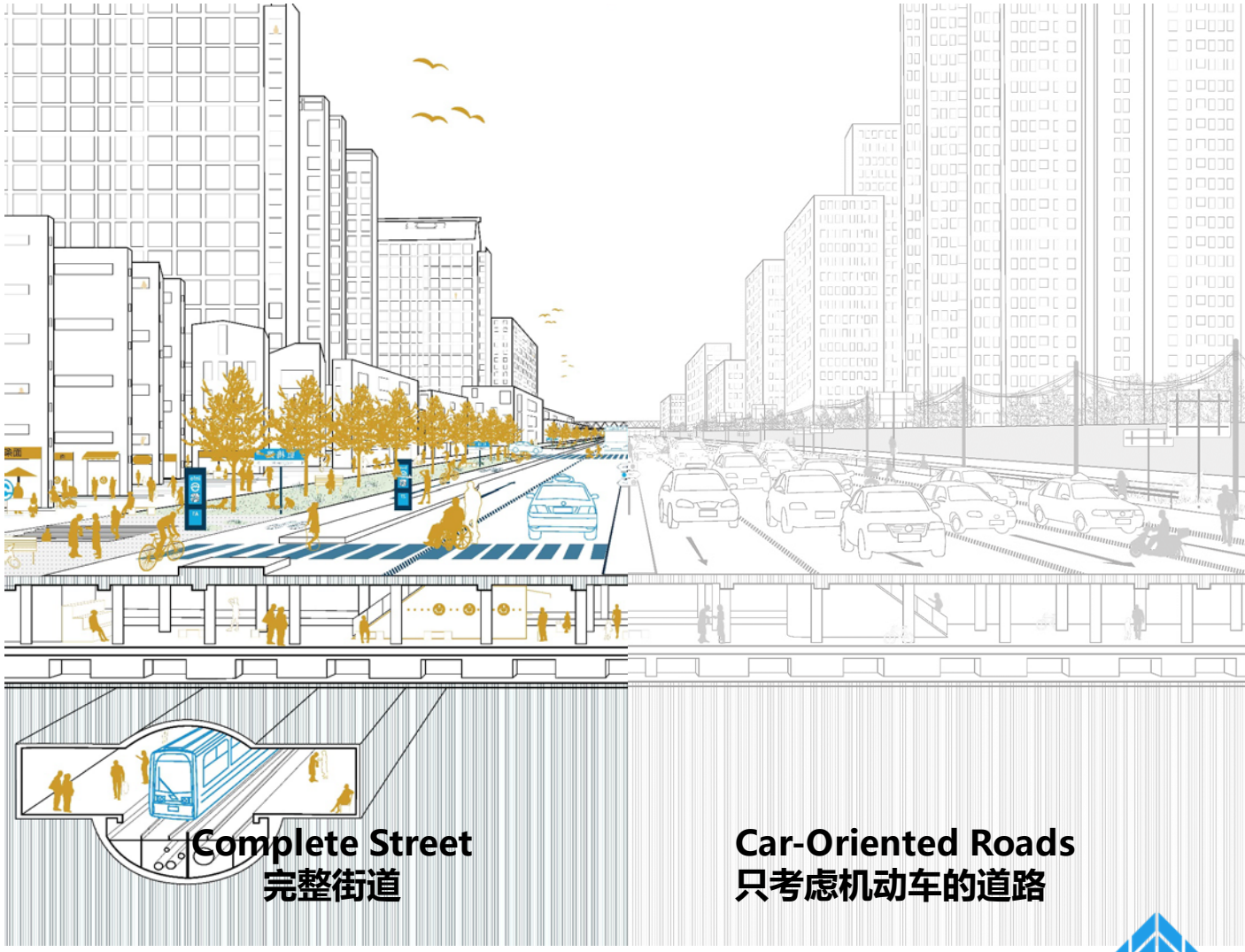
	AQI				
(Coefficient)	Annual	Spring	Summer	Fall	Winter
Meteorology					
Average daily precipitation	−0.150**	−0.051	−0.032*	−0.052	−0.678*
	(0.067)	(0.042)	(0.018)	(0.058)	(0.272)
Average daily temperature	0.147**	0.124*	0.117*	0.004	0.089
	(0.070)	(0.073)	(0.064)	(0.067)	(0.076)
Average daily wind speed	−0.743**	−0.553**	−0.233	−0.727**	−1.304***
	(0.267)	(0.244)	(0.289)	(0.295)	(0.398)
Energy and industry					
Central Heating Provision	10.484***	9.234***	–	–	14.559**
	(4.129)	(4.008)			(7.206)
Log of Gasoline Coverage	1.073	0.485	0.799	1.618*	0.814
	(0.797)	(0.786)	(0.736)	(0.931)	(1.379)
Second Industry as % GDP	0.070	−0.006	0.190*	−0.059	0.111
	(0.108)	(0.106)	(0.101)	(0.128)	(0.189)
Urban form					
Population Density	3.996	6.172*	−3.762	8.155*	4.058
	(4.112)	(4.069)	(3.831)	(4.835)	(7.192)
Log of Urban Area	4.113**	3.441**	3.050*	5.609***	7.057**
	(1.687)	(1.636)	(1.565)	(1.944)	(2.883)
Green Space Coverage	−2.794**	−3.644***	−0.240	−0.342	−5.209**
	(1.385)	(1.369)	(1.289)	(1.628)	(2.412)
Road Area Coverage	0.410*	0.145	0.299	0.552*	0.808*
	(0.245)	(0.242)	(0.227)	(0.285)	(0.425)
Street Network Density	−0.597	−0.162	−0.633	−1.089*	−1.065
	(0.477)	(0.472)	(0.441)	(0.558)	(0.831)
Bus Coverage Ratio	−6.837	−5.928	−1.318	−7.187	−13.494
	(6.155)	(6.067)	(5.849)	(7.183)	(10.653)
Rail TOD Index	−0.342**	−0.335**	−0.159	−0.485***	−0.477*
	(0.143)	(0.140)	(0.134)	(0.167)	(0.247)
BRT TOD Index	0.140	0.080	0.226	0.003	0.645
	(0.367)	(0.360)	(0.343)	(0.431)	(0.637)
Constant	73.354***	76.354***	36.147	65.562***	124.876***
	(18.838)	(19.975)	(22.315)	(20.682)	(27.140)
Lambda	0.779***	0.813***	0.720***	0.767***	0.781***
Observations	152	152	152	152	152
Pseudo R2	0.685	0.707	0.549	0.583	0.666
Log Likelihood	−586.667	−587.045	−571.834	−610.369	−671.245
sigma2	110.04	107.794	93.979	151.643	334.445
Akaike Inf. Crit.	1207.33	1208.09	1175.67	1252.74	1376.49
Wald Test (df = 1)	310.196***	442.647***	180.358***	273.825***	315.606***
LR Test (df = 1)	78.961***	87.897***	55.538***	92.661***	93.170***

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Measuring Street Space in China

2

Why Measuring Street Space…



Street View Image Processing

Street Space Indicators

Sidewalk existence X_1

Bike lane existence X_2

Crossing facility existence X_3

% Sidewalk with illegal parking X_4

% Bike lane with illegal parking X_5

% Street with tree shade X_6

Street width X_7

Bike lane isolation X_8

Street wall continuity ratio X_9

Street network density X_{10}

Crossing density X_{11}

Facility accessibility X_{12}

>> Identify sidewalks and bike lanes from street view images

Street Space Indicators

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>> Identify crossing facilities from street view images

> Crossing facilities include zebra strips, signal lamps, overpass and underpass

> Multiple types of crossing facilities at the same spot count as one facility

Street Space Indicators

>> Estimate the proportion of sidewalks/bike lanes occupied by illegal car parking from street view images

Sidewalk existence X_1

Bike lane existence X_2

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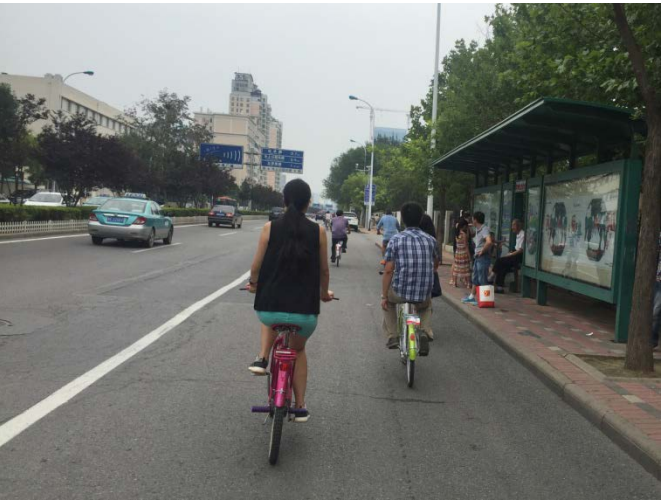
Street Space Indicators



Striping
Score: 1

Fence
Score: 2

Median
Score: 3

>> Identify the forms of bike lane isolation from street view images

Sidewalk existence X_1

Bike lane existence X_2

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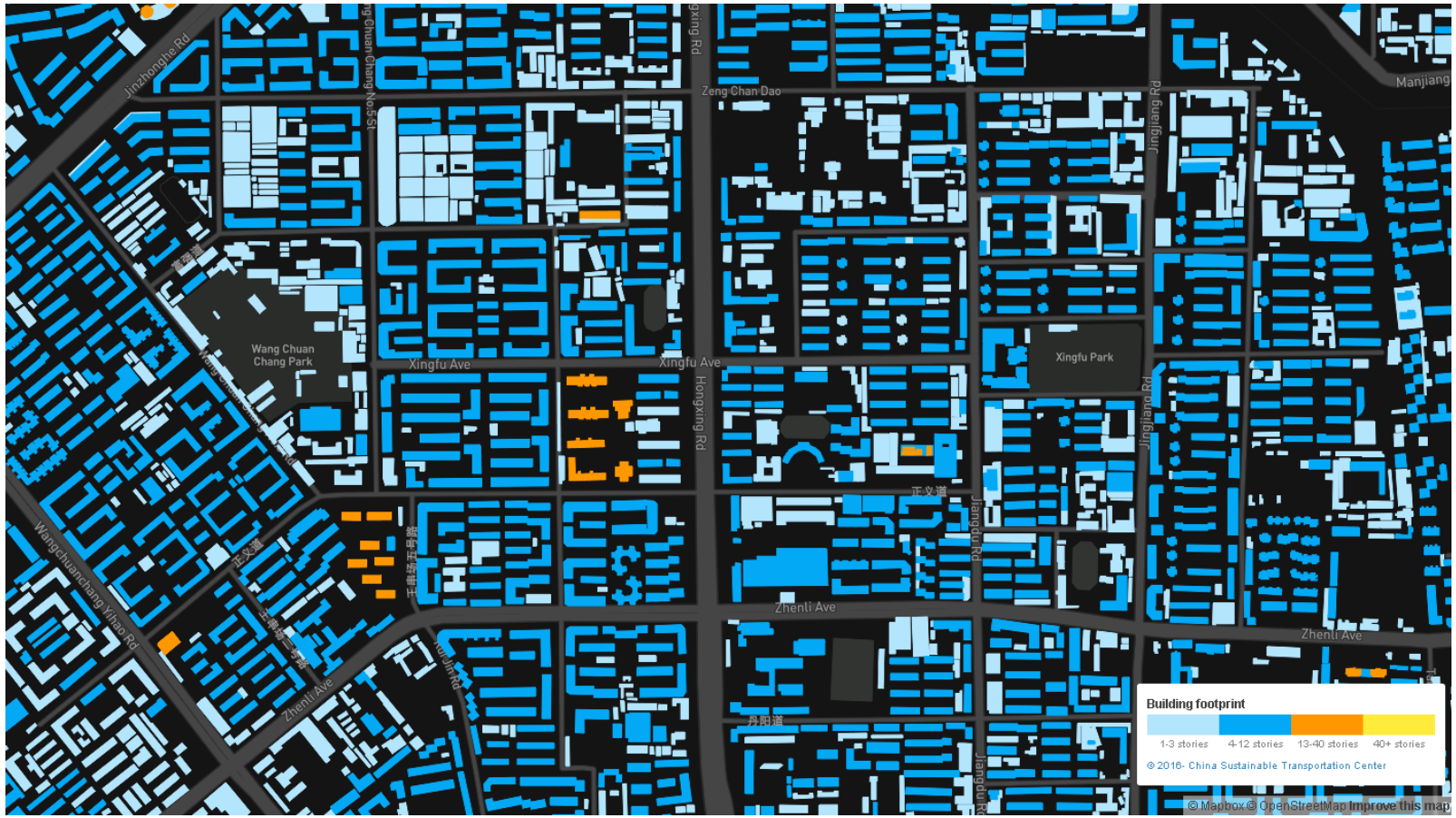

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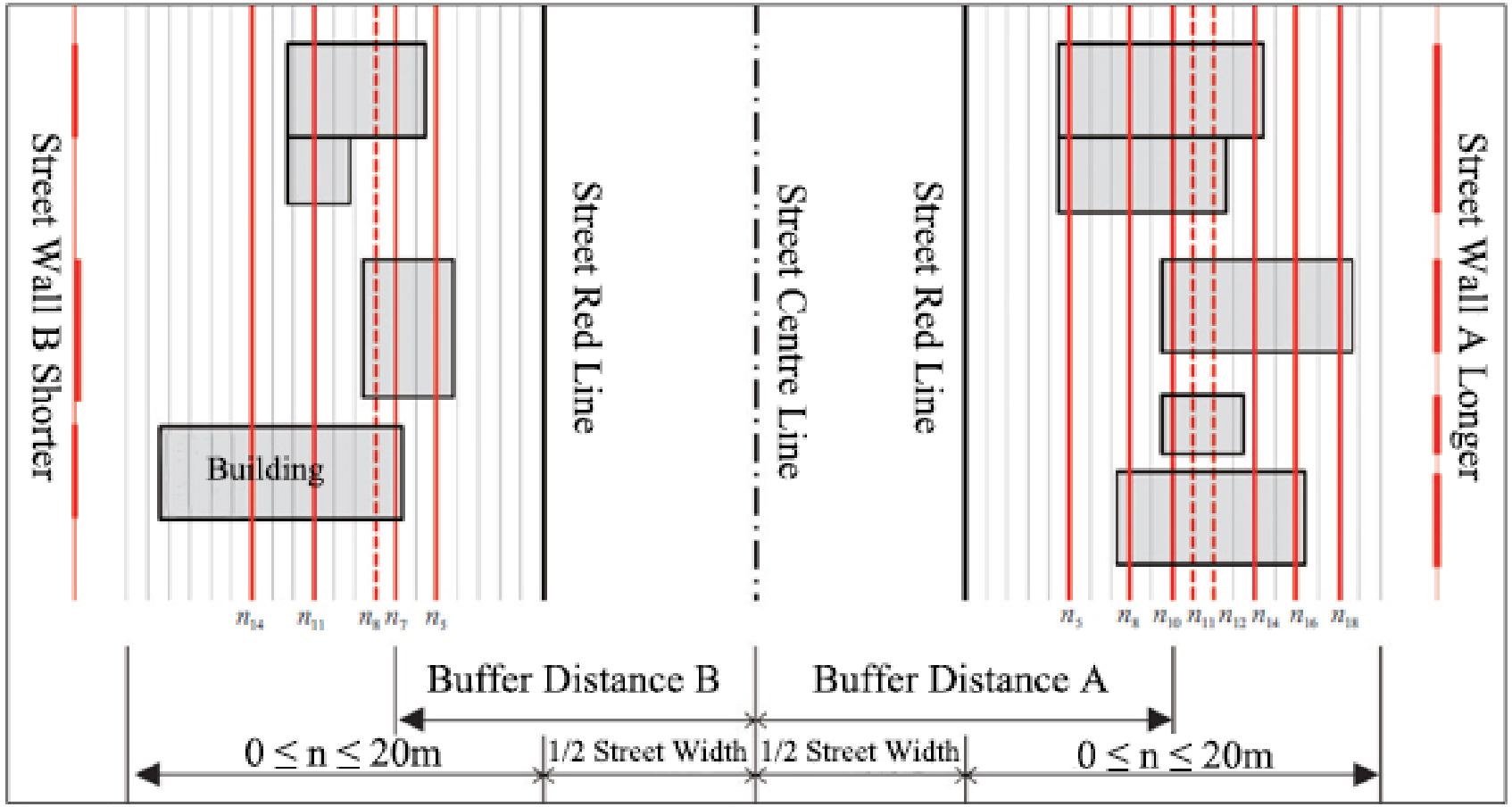
Facility accessibility X_{12}

>> Identify street façade using building lots

Street Space Indicators



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Street network density X_{10}

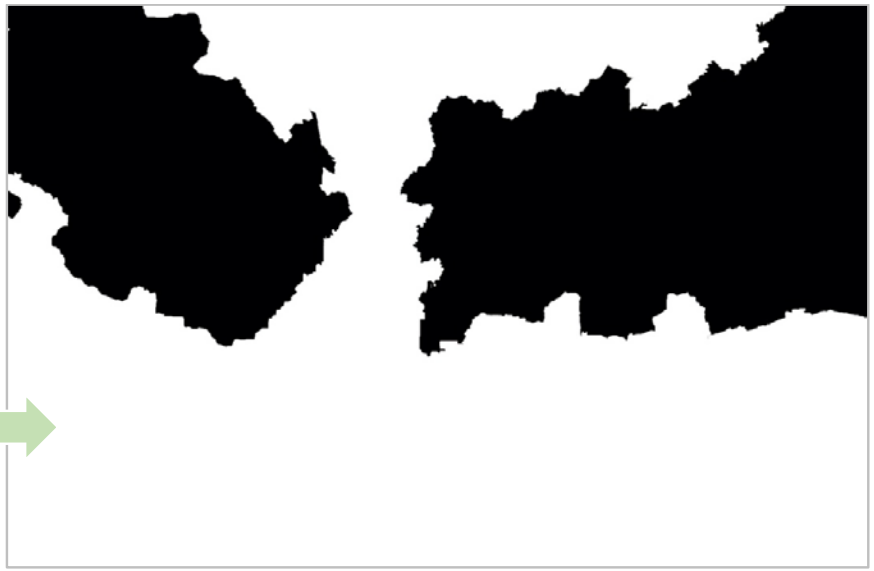
Crossing facility density X_{11}

Facility accessibility X_{12}

>> Using maximum intersection method based on arcpy library of ArcGIS to calculate the street-wall continuity ratio

>> Calculate street width as the distance from the street's center line to the building facades on both sides (adapted from Harvey,2014)

Street Space Indicators



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Street network density X_{10}

Crossing facility density X_{11}

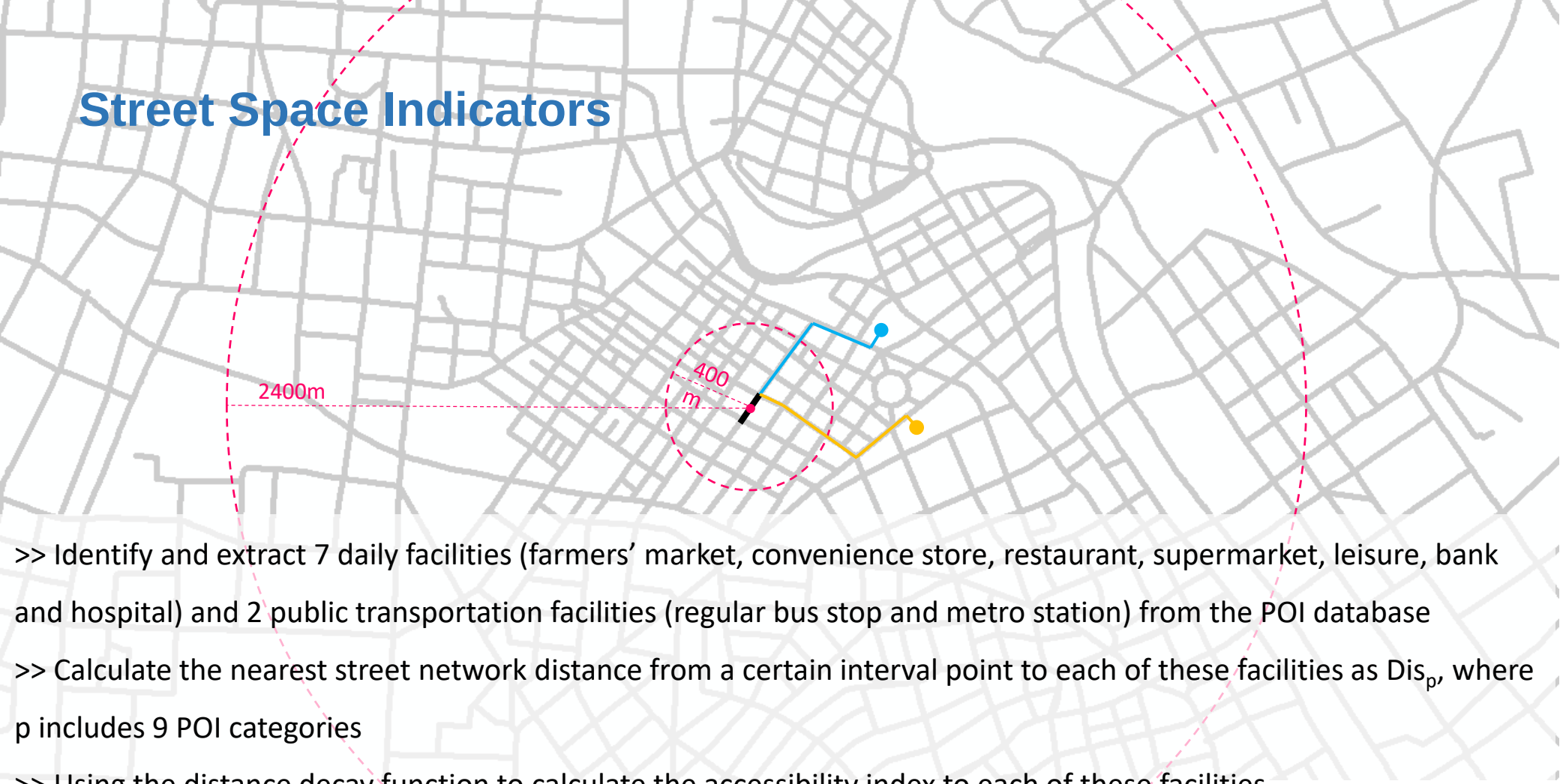
Facility accessibility X_{12}

>> Extract the green pixels from street view images (SVI) based on a manually set greenness color range

>> Calculate the average green view index (GVI) of each interval point using the greenness proportion from four-direction SVI

>> Estimate %street with tree shade with the mean GVI of all interval points on a street segment

Street Space Indicators



>> Identify and extract 7 daily facilities (farmers' market, convenience store, restaurant, supermarket, leisure, bank and hospital) and 2 public transportation facilities (regular bus stop and metro station) from the POI database

>> Calculate the nearest street network distance from a certain interval point to each of these facilities as Dis_p, where p includes 9 POI categories

>> Using the distance decay function to calculate the accessibility index to each of these facilities

$$Acc_p = \begin{cases} 0 \ , \text{if } Dis_p > 2400 \\ 1 \ , \text{if } Dis_p \leq 400 \\ 188177 * \frac{Dis_p}{(Pow(Dis_p, 2.9475) + 34259163)}, \text{if } 400 < Dis_p < 2400 \end{cases} \quad (1)$$

Then, the average facility accessibility for each interval point was calculated:

$$Acc = \sum_1^9 Acc_p * 1/9 \quad (2)$$

Adapted from Lu (2013)

Sidewalk existence X_1

Bike lane existence X_2

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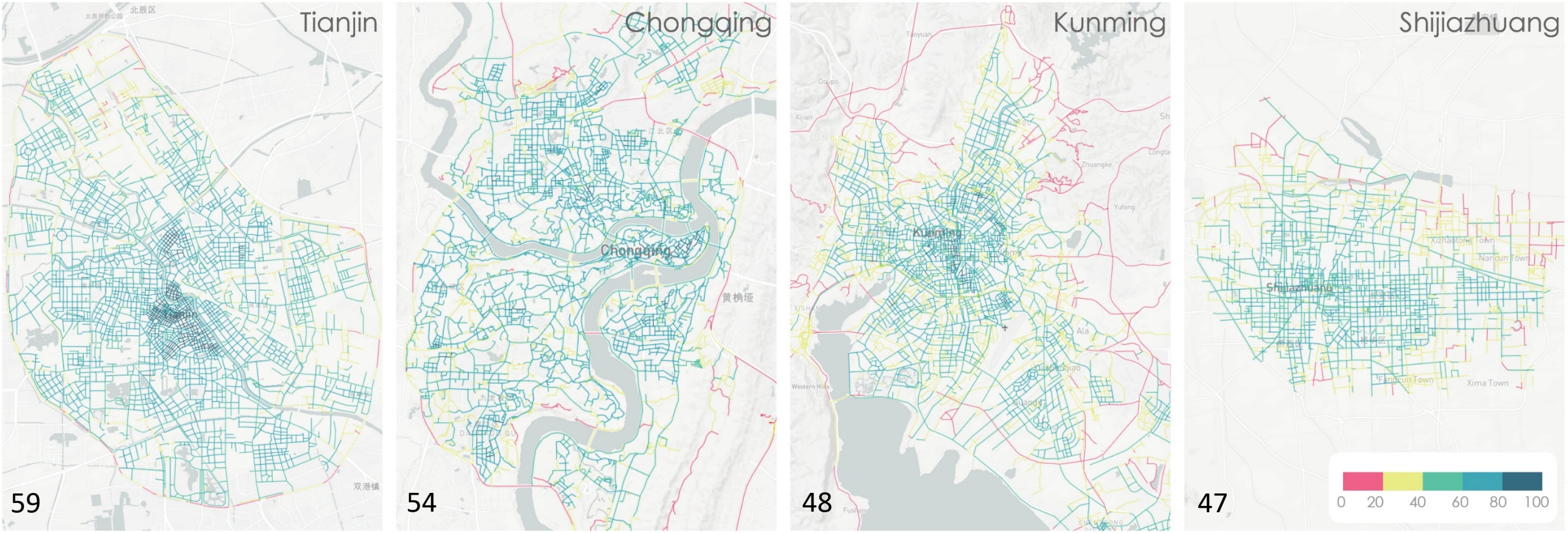
Facility accessibility X_{12}

Street Space Indicators

Dimension	Indicator	
	Walkability	**Bikeability**
Safety	Sidewalk existence (+)	Bike lane existence (+)
	Crossing facility existence (+)	
	% Sidewalk with illegal parking (-)	% Bike lane with illegal parking (-)
Comfort	% Street with tree shade (+)	
	Street width (-)	Bike lane isolation (+)
	Street wall continuity ratio (+)	
Convenience	Street network density (+)	
	Crossing facility density (+)	
	Facility accessibility (+)	

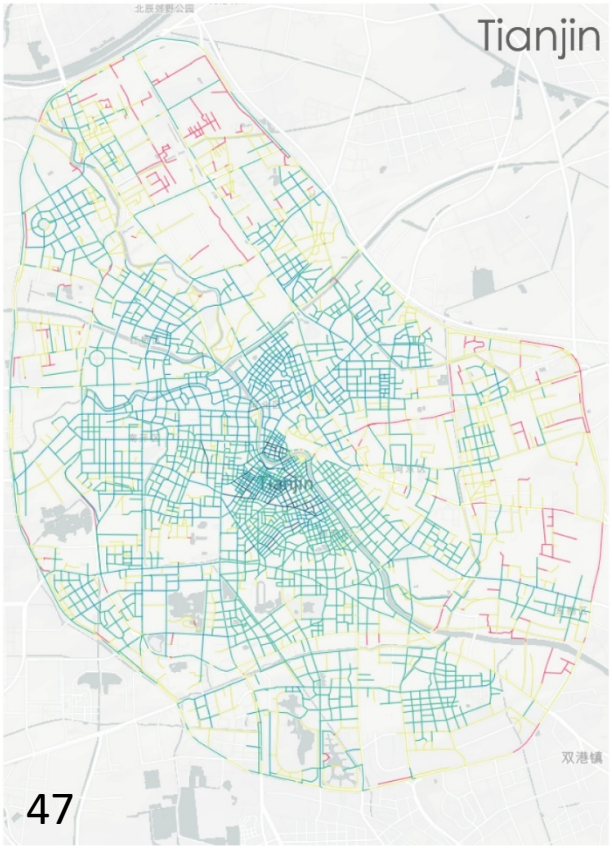
Indicators marked as “+” imply a positive relationship with street score, while indicators marked as “-” imply a negative relationship with street score.

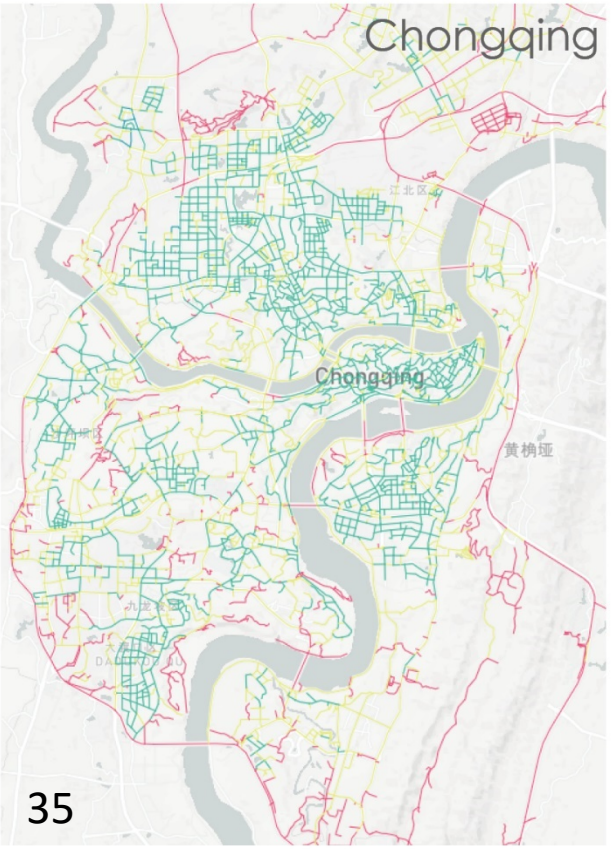
Street WALK Score

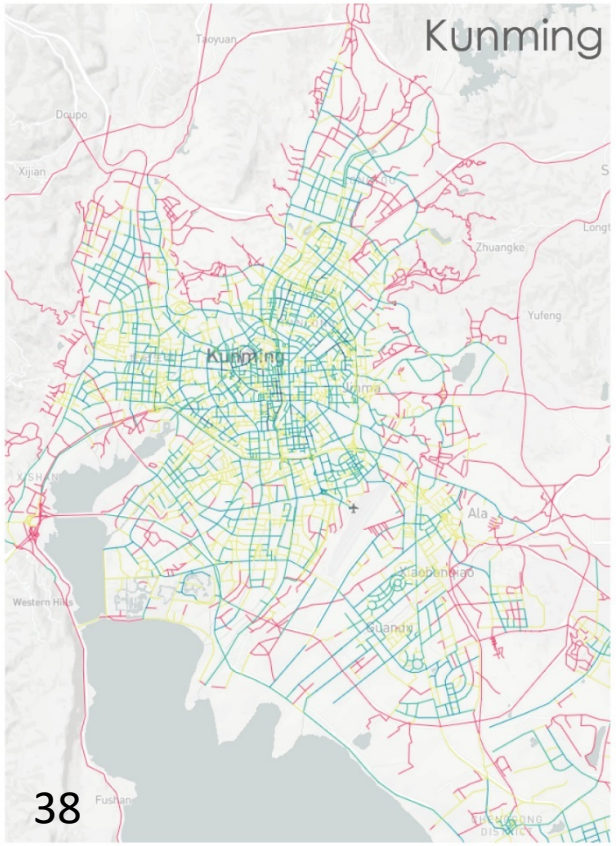


>> Clusters of high-walkability streets forms in city centers, while in periphery areas, street walkability fades out.

Street BIKE Score







>> The overall bike scores are lower than walk scores;

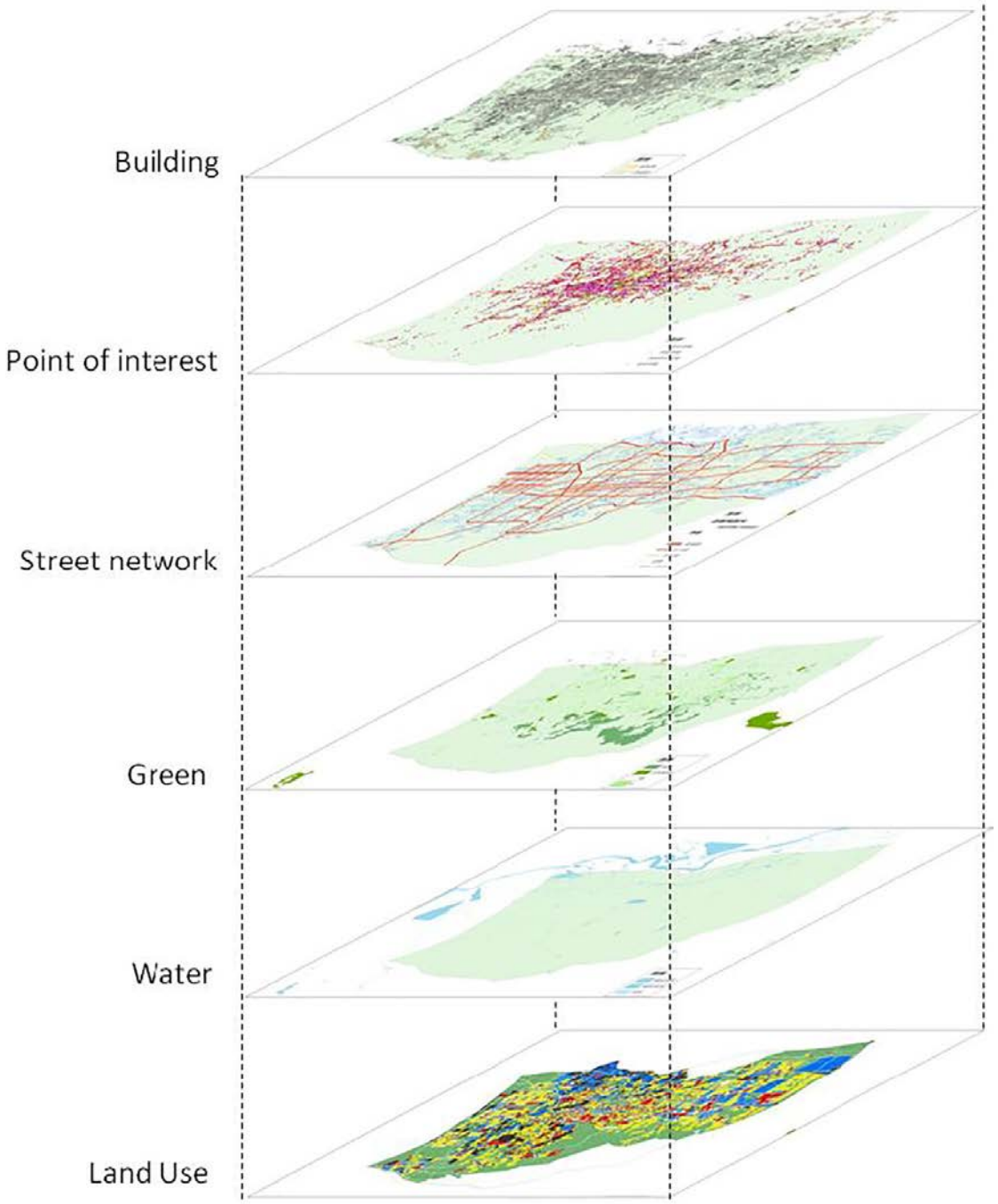
>> A preliminary bikeable street network is evident in Tianjin, Kunming and Shijiazhuang.

Modelling CO2 Emissions in Jinan, China

3

Case Study: Jinan

City population: 3.4 million
Study area: 533 sq. km



An integrated GIS Database for Jinan

Jinan Household Survey

2,540 households from 104 neighborhoods
Socio-demographics, weekly travel dairy, attitudes

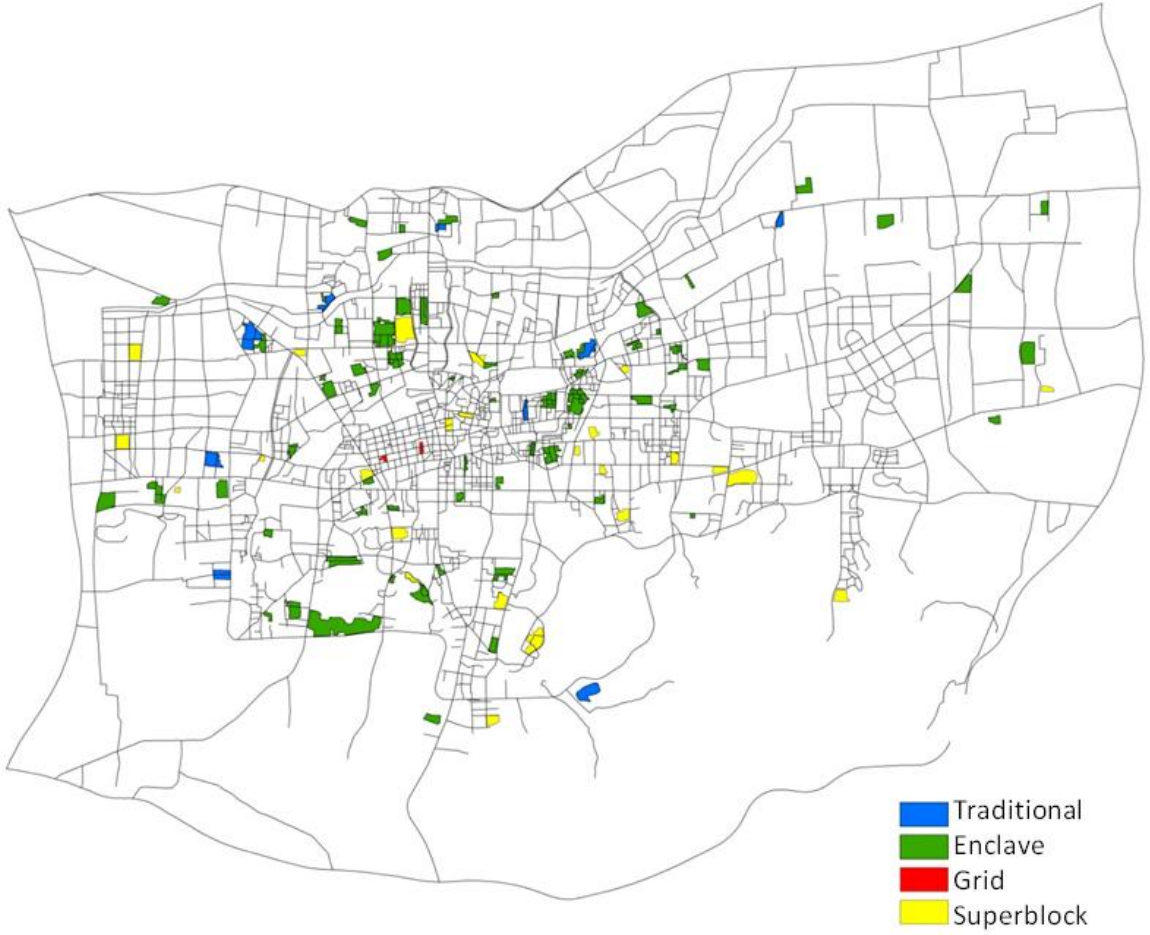


Table 1
Comparisons of household characteristics between the survey sample and city population in Jinan.

	Survey sample	City average
Household size (persons)	3.01	2.98
Household income (RMB/year)	33,873	38,763
Car ownership (cars/100 people)	20.5	19.6
Mode share- car	19%	15%
More share- bus	17%	18%

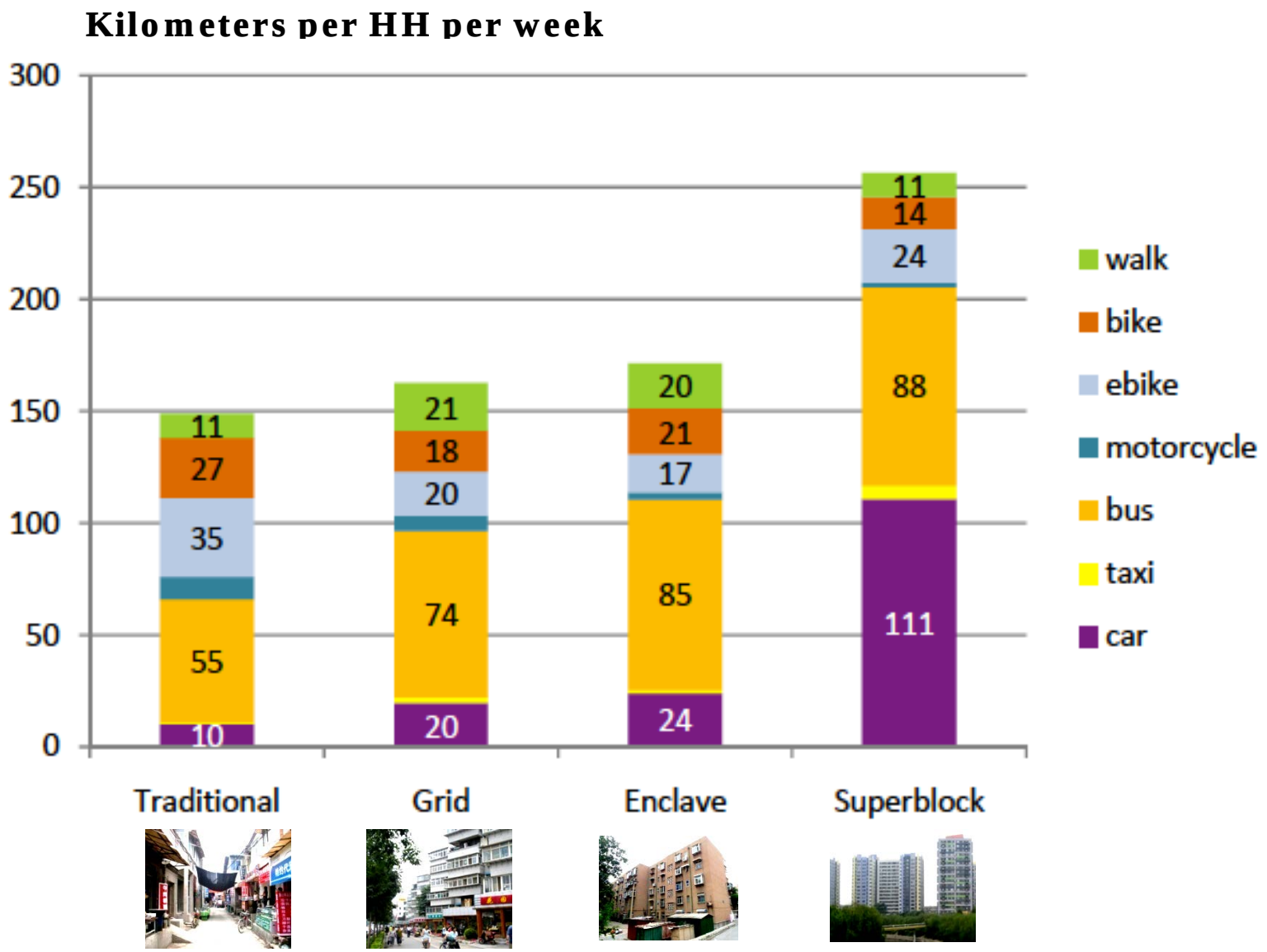
Traditional

Grid

Enclave

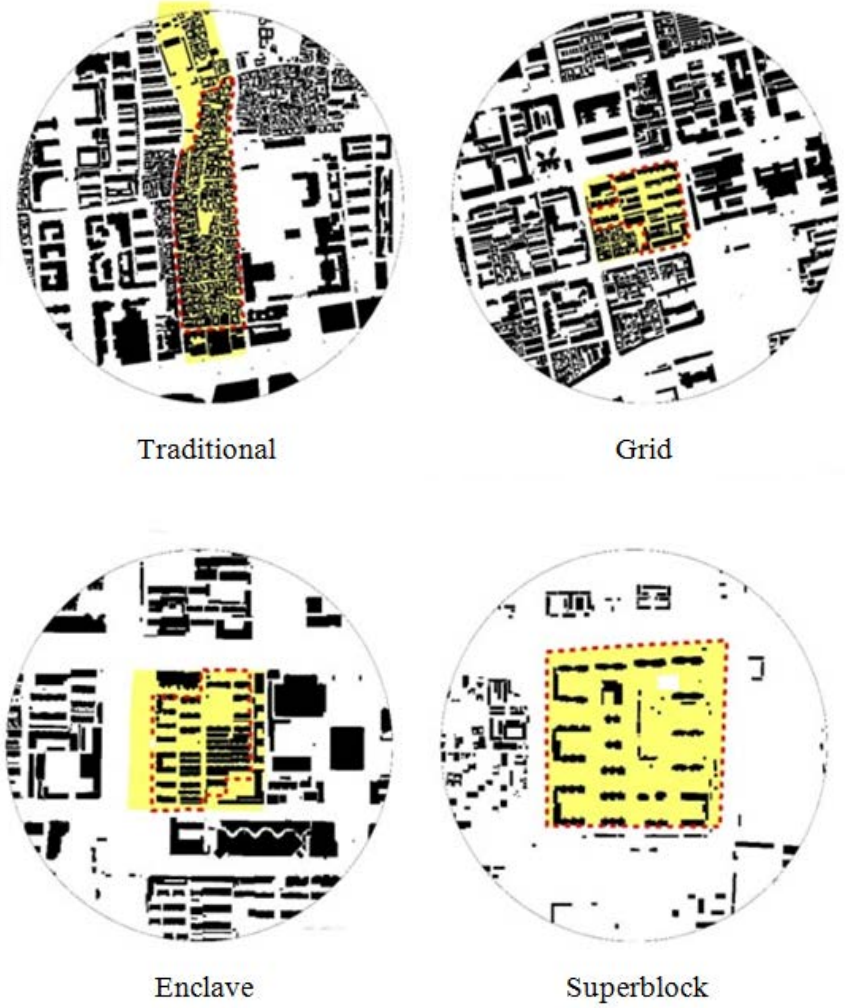
Superblock

Travel Distance by Neighborhood Types



Urban Form/Street Space Indicator Framework

	Urban Form	Street Space
Density	Floor area ratio	Street network density
	Building coverage	Density of crossing facilities
	Population density	Density of ground floor retails
Diversity	Land use mix index	% of streets with dedicated bus lanes
	Number of POIs	% of streets with bike lanes
	Job-housing balance	% of streets with sidewalk Street right of way mix index
		Density of bus stops
Design	Land area	Building setback distance
	Parking lots per household	% of streets with tree shade
	Distance b/w entrances	Street wall continuity
		% of streets with curbside parking % of streets with illegal parking



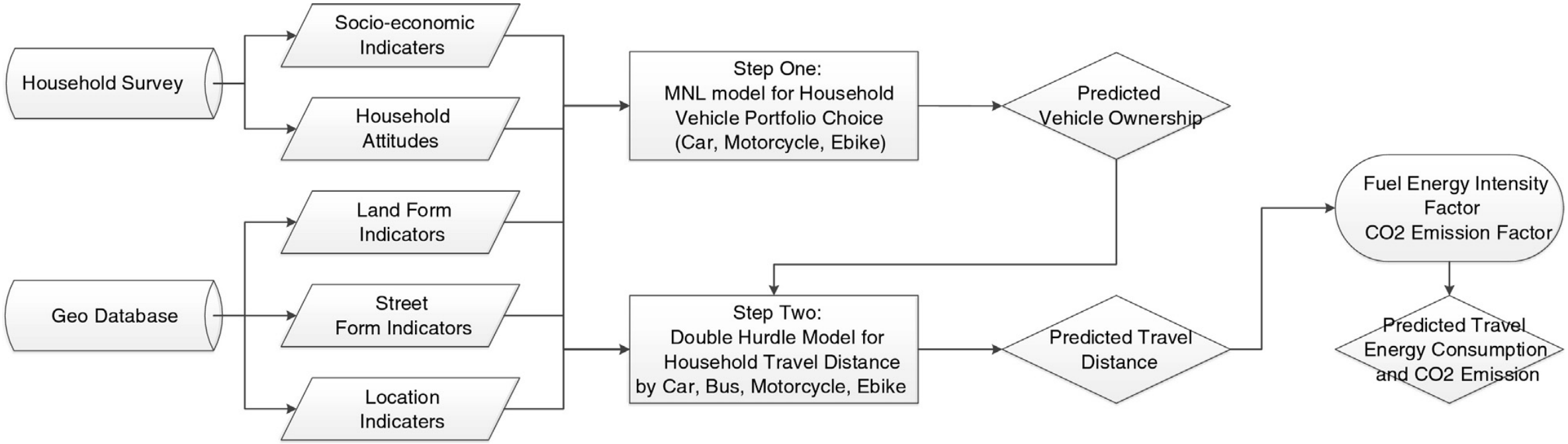
Direct Modelling Approach

- Principle component analysis
- Household vehicle portfolio choice model
- Household travel distance models

Table 3
Fuel energy intensity and CO_2 emission factor values in Jinan, China.

Mode	Energy consumption factor[a] (mj/veh·km)	CO_2 emission factor[a] (kg/veh·km)	Trip occupancy rate[b] (person/veh)
Car	2.962	0.199	1.3
Bus	10.680	0.741	18.0
Motorcycle	0.612	0.041	1.1
Ebike	0.076	0.026	1.1

[a] Based on Cherry, Weinert, and Xinmiao (2009) and Jiang et al. (2015).
[b] Trip occupancy rates for car, motorcycle and ebike were derived from the household sample. The trip occupancy rate for bus was obtained from Jiang et al. (2015).



Direct Modelling Approach

Household travel distance model: Double-Hurdle Model

- account for the excess number of zero values in the distributions of dependent travel distance variables

- **Stage 1 choice model** categorizes households as either generating any distance or not.
- It contains a participation equation where the latent variable d* represents, in this case, the decision to travel as a linear function of first-hurdle regressor (z),

$$d^* = \alpha' z + u \qquad u \sim \mathbf{N}(0,1) \tag{1}$$

- **Stage 2 distance model** estimates the **log-transformed VKT** generated for households with any(positive) VMT. It features a consumption equation, characterized by the latent variable y*, the distance travelled, as a linear function of second-hurdle regressors (x).

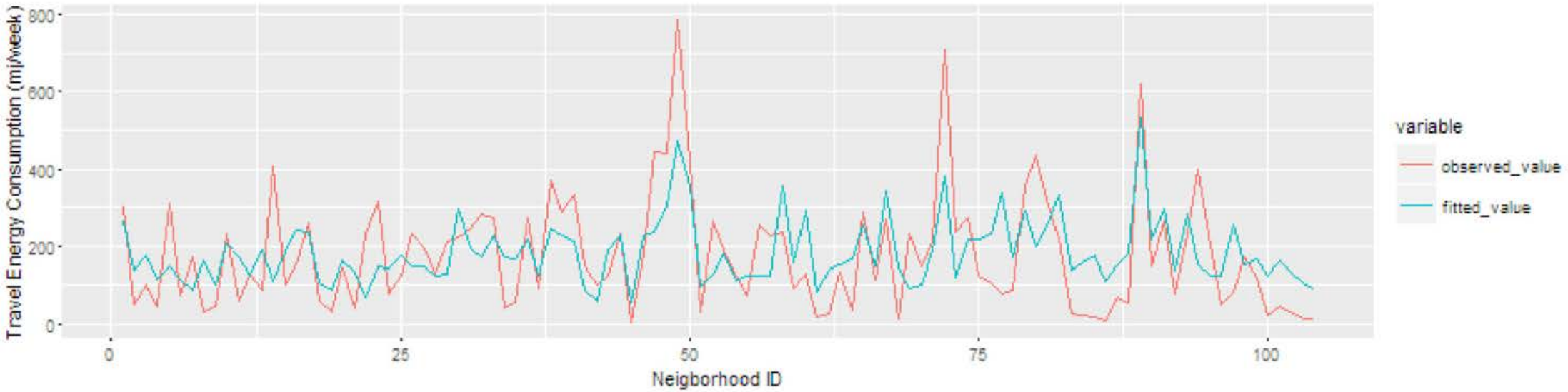
$$y^* = \beta' x + v \qquad v \sim \mathbf{N}(0,1) \tag{2}$$

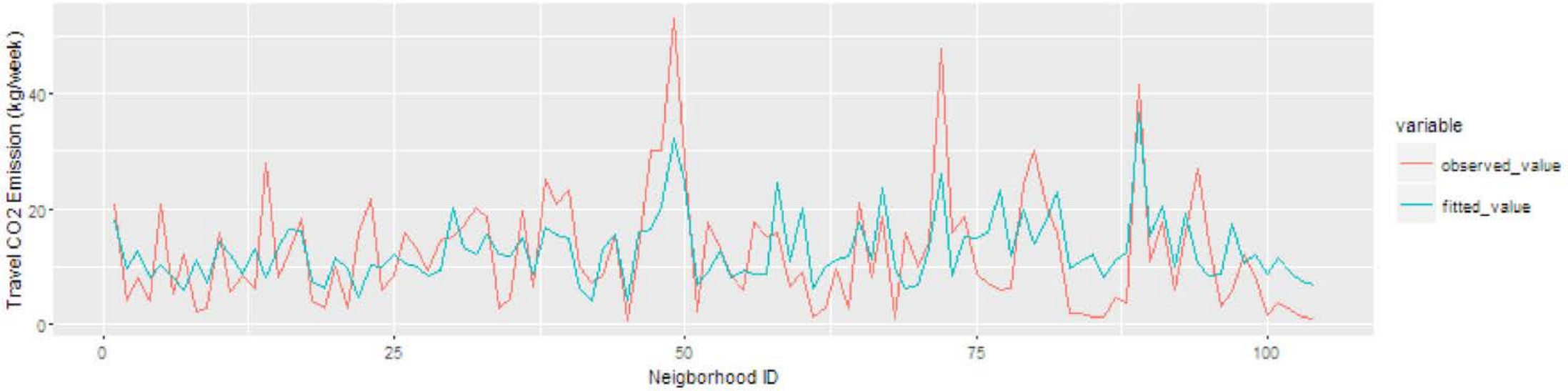
- Thus the observed distance traveled y:

$$y = \begin{cases} y^*, & \text{if } d^* > 0 \text{ and } y^* > 0 \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

- The “vehicle owned” variable will be replaced by the predicted values from the Ownership MNL model.

Hold-out Validation





Conclusion and Discussion

4

Conclusion

- Part I: A TOD performance indicator system reflecting the quantity and quality dimensions was developed and composite TOD indexes were estimated for 37 Chinese cities with either urban rail or BRT systems. The rail TOD index correlates negatively with air pollution concentrations measured by annual and seasonal average AQIs (except for the summer average AQI).

- Part II: Utilizing open source data, we put forward a methodology to comprehensively and objectively measure street walkability and bikeability in China.

- Part III: Through the Jinan case, we demonstrated advantages of a direct modelling approach for CO2 assessment:
  - ✓ Provides flexibility on data requirements
  - ✓ Captures the effects of both the land form and street form variables on travel outcomes
  - ✓ Integrates the vehicle ownership portfolio choice model and the travel distance models, so that it produces travel behavior outcomes to assist story-telling and to have potential for extension to additional impact analysis (e.g., NOx emissions)
  - ✓ Uses a holdout validation to address the over-fitting problem of models and to enhance its reliability and robustness for assessing future scenarios under the local context

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Transit-oriented development and air quality in Chinese cities: A city-level examination

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ABSTRACT

In this paper, we aim to see whether transit-oriented development (TOD) in Chinese cities is associated with better air quality. We first identify 37 Chinese cities with existing urban rail transit and/or bus rapid transit (BRT) systems. For each of these cities we generate performance-based TOD indicators – including measures such as urban area coverage, population coverage, street network density and land use mix within station catchment areas – and construct composite TOD indices for each city using those indicators. We also collect daily air quality index (AQI) data from the Ministry of Environmental Protection of China over the entire year 2014 for 152 cities and calculate annual and seasonal average AQIs for each city. Regression models provide some evidence that rail-based TOD is associated with better air quality, after controlling for meteorological, demographic and economic characteristics. BRT-based TOD shows no significant relationship.

1. Introduction

China's urban air pollution, accompanying the nation's rapid economic development and urbanization, has generated increasing concerns (Hao and Wang, 2005; Fang et al., 2009). Among the factors contributing to the severe air quality threats, increasing dependence on private vehicles and growing traffic congestion in cites have become critical. Transit-oriented development (TOD) is often espoused as an effective solution to promoting "green" travel among urban residents and to shaping cleaner cities. However, little empirical research explicitly links urban air quality and TOD. We might expect TOD to be related to better urban air quality because TOD aims to increase the use of public transportation which tends to have lower rates of local pollutants per distance traveled per person than automobiles, to increase walking and bicycling use, and to decrease average trip distances.

While some scholars have explored the relationship between urban air quality and the built environment, they have mainly measured the intra-urban heterogeneity of air pollutant concentrations in specific cities. In this paper, we aim to answer the following questions. Are cities with a higher degree of TOD in China associated with better air quality? Is there a difference in this relationship depending on whether the TOD is rail-based versus bus rapid transit (BRT)-based? We attempt to answer these questions by modeling urban air quality in a sample of Chinese cities as a function of measures of TOD and controlling for other factors, including meteorological conditions, demographic and economic conditions, and urban form. The following section reviews the relevant

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Using Open Source Data to Measure Street Walkability and Bikeability in China: A Case of Four Cities[AQ: 1]

Peiqin Gu[1], Zhiyuan Han[1], Zhejing Cao[2], Yulin Chen[2], and Yang Jiang[1]

Whether people would choose to walk or ride a bike for their daily travel is affected by how desirable the environmer for walking and biking. To better inform urban planning and design practices, studies on, and tools for measuring, walkab and bikeability have emerged in western countries over the last decade. However, such efforts are still rare in develo countries, partially due to the scarcity of urban data. Utilizing open source data, this paper puts forward a methodol to comprehensively and objectively measure street walkability and bikeability in China. The methodology was applied four Chinese cities: Tianjin, Chongqing, Kunming, and Shijiazhuang. Analyses showed the following results: (1) city cent tend to have higher walkability than periphery areas; (2) a preliminary bikeable street network exists in most cities (exc mountainous cities), but the prevalence of bike lanes on streets is much lower than that of sidewalks; (3) the problem of ill parking on both sidewalks and bike lanes is severe, especially in city centers; (4) biking safety and comfort is compromi due to a lack of physically separated bike lanes; and (5) the street wall continuity varies from place to place whereas the str network in traditional city centers is much denser than newly developed car-oriented areas. The end of the paper provi corresponding policy implications.

As car-oriented urban development during past decades has caused severe traffic jams and air pollution in China, the public is starting to realize that streets are an important public space in daily life and is paying more attention to the non-motorized transportation environment. With the emerging popularity of bike-sharing businesses in China, the mismatch between biking demand and the supply of street space for biking has never before been so striking. In fact, the central government of China published *China's Urban Pedestrian and Bicycle Transportation System Planning and Design Technical Guideline* in 2013 (*1*). Chinese cities have also turned their attention to non-motorized transportation very recently; for instance, Shanghai published the *Shanghai Street Design Guideline* in 2016 (*2*).

In theory, whether people choose to walk or ride a bike for their daily travel should be affected by how desirable the environment is for walking and biking. Although the literature has supported this with rich empirical evidence, it is often limited in the following aspects: the coding of comprehensive street design could only be done at a small scale due to labor intensity (*3, 4*); the crowd-sourcing of residents' opinions on the walk and bike environments are criticized as lacking objectivity (*5, 6*); the existing street score evaluations tend to ignore detailed design components (*7, 8*); there are still few studies measuring street bikeability (*9, 10*); and there are still limited approaches that can be linked with the Chinese urban context (*11–13*). In the practical world, ur planners and policy makers are urging a comprehensive objective approach to measuring walkability and bikeabi that can guide real-world planning and design exercises.

How can we massively quantify street planning design indicators to measure street environments for wa ing and biking in China? To answer this question, a me odology utilizing open source data was put forward comprehensively and objectively measure street walka ity and bikeability in China. The methodology was appl to four Chinese cities: Tianjin, Chongqing, Kunming, Shijiazhuang. The remainder of the paper is organized follows. First existing street scoring methodologies their applications are reviewed. The paper then expla how all individual indicators were processed and how framework was developed using the information entro weighting method. Next, the overall score results and s tial patterns of individual indicators for the four cities illustrated. The paper concludes with the findings and icy recommendations.

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Modelling household travel energy consumption and CO_2 emissions based on the spatial form of neighborhoods and streets: A case study of Jinan, China

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ABSTRACT

This paper presents a direct modelling approach to evaluate household travel energy consumption and CO_2 emissions based on the spatial form of neighborhoods and streets. It integrates one multinomial logit model and four double hurdle models to predict travel outcomes: vehicle ownership portfolio choice, car travel distance, bus travel distance, motorcycle travel distance and ebike travel distance. The energy consumption and CO_2 emissions are then estimated using these travel outcomes. A full application of the modelling approach is demonstrated through a pilot project in Jinan, China. A holdout validation is also performed to address the over-fitting problem of models calibrated from the training set data. Results show that the proposed approach is operational and appropriate for sketch planning applications to promote clean energy and low carbon city planning in urbanizing China.

1. Introduction

Climate change and the energy crisis are two major challenges that humans face in the 21st century. Among all sectors, the transportation sector is expected to undertake the fastest increase in size in the next 30 years, with the majority of growth contributed from non-OECD countries and a significant part from road transport (De la Rue du Can & Price, 2008; IEA, 2007). With the rapid development of urbanization and motorization, the road transport oil consumption in China has increased by 9% annually from 1995 to 2005, and will be four times the present level in 2030 if the trend continues (He et al., 2005); a picture that raises concerns over urban air pollution, national oil security and global warming.

To mitigate energy consumption and carbon emissions from road transport in cities, China has been taking measures focusing on the end-of-pipe treatment, such as promoting clean fuels and electric vehicles and adopting stricter fuel economy standards (Bradsher, 2009; Yan & Crookes, 2009). Yet international scholars have suggested that supply-oriented technical solutions alone are unlikely to be sufficient to achieve the desired reductions; also required are urban policy measures that can facilitate citizens' travel patterns to avoid automobile dependency on the demand side (Guan, Hubacek, Weber, Peters, & Reiner, 2008; Mui, Alson, Ellies, & Ganss, 2007; Pacala & Socolow, 2004; Wright & Fulton, 2005; Yan & Crookes, 2010; Zeng, Ding, Pan, Wang, & Gregg, 2008). The latter is particularly critical for China where the urbanization is fast paced and the motorization level is still low compared to western countries. However, physical development of wide roads, segmented function zones and superblock neighborhoods in Chinese cities appears to create lock-in effects of car-dependence for future generations (Jiang, Zegra, Mao, & He, 2015; Pan, Shen, & Zhang, 2009). Alternative spatial planning and implementation, therefore, are key to tackling the energy and climate change challenges faced by the road transport sector in China.

Unfortunately, the urban energy and carbon modelling communities seem to have not yet grasped this remarkable opportunity for China. Although relevant modelling work in western countries has enjoyed the advantage of robust theories and sophisticated methods, they rarely incorporated the effect of urban form in practical ways (Bartholomew & Ewing, 2009; Wegener, 2011). This might not be a significant problem given that urbanization in the western countries is slow and even stagnant compared with the developing world. But applying such sophisticated models in China, regardless of their implementation difficulties, cannot meet the demands of policymakers concerned with large-scale urban growth or retrofit. Furthermore, the scarcity of data and empirical studies in China has undermined the possibility of reliable self-developed models (Zhou & Wang, 2014).

The objective of this research is to develop a direct modelling approach to evaluate household travel energy consumption and carbon

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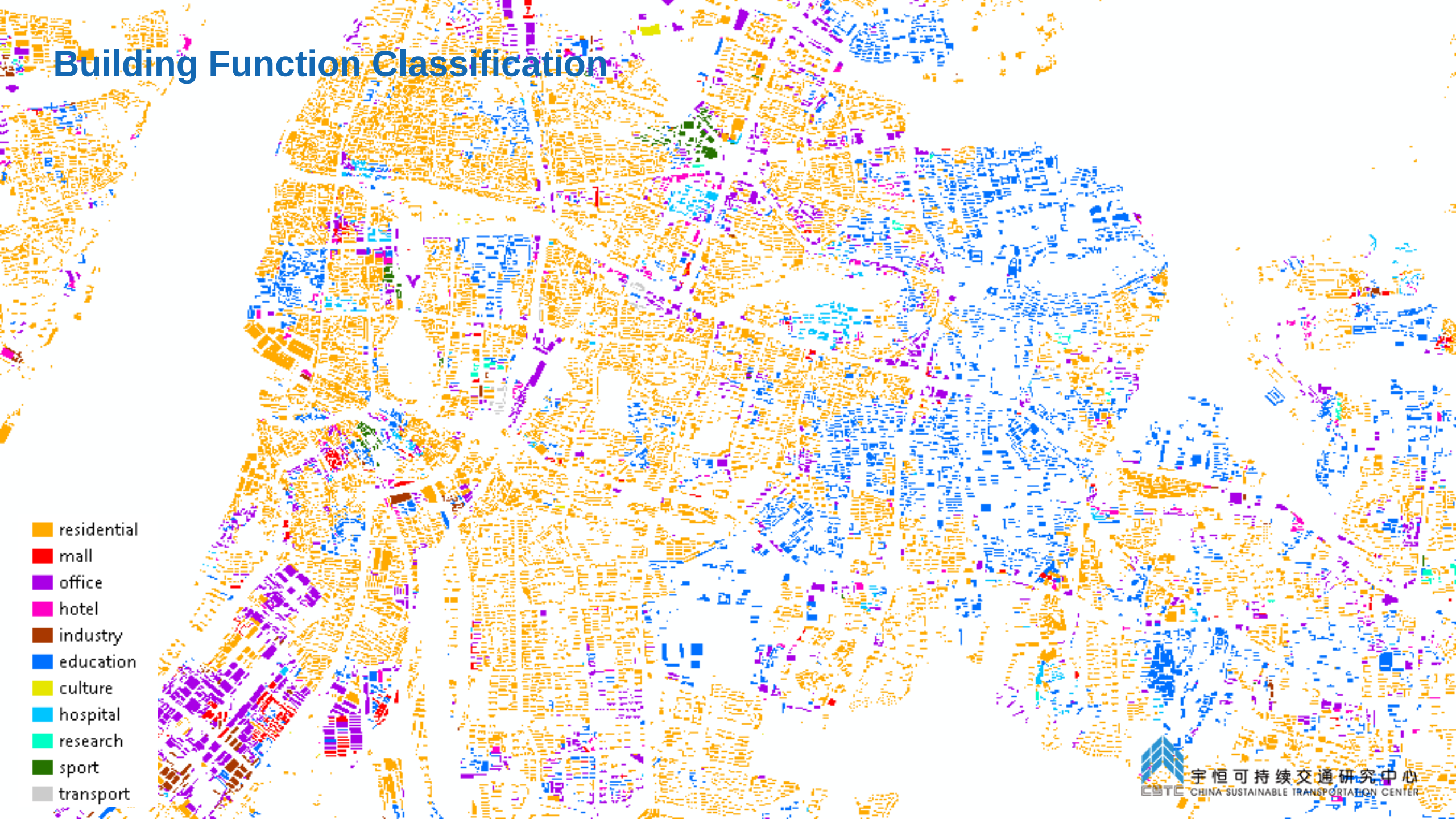
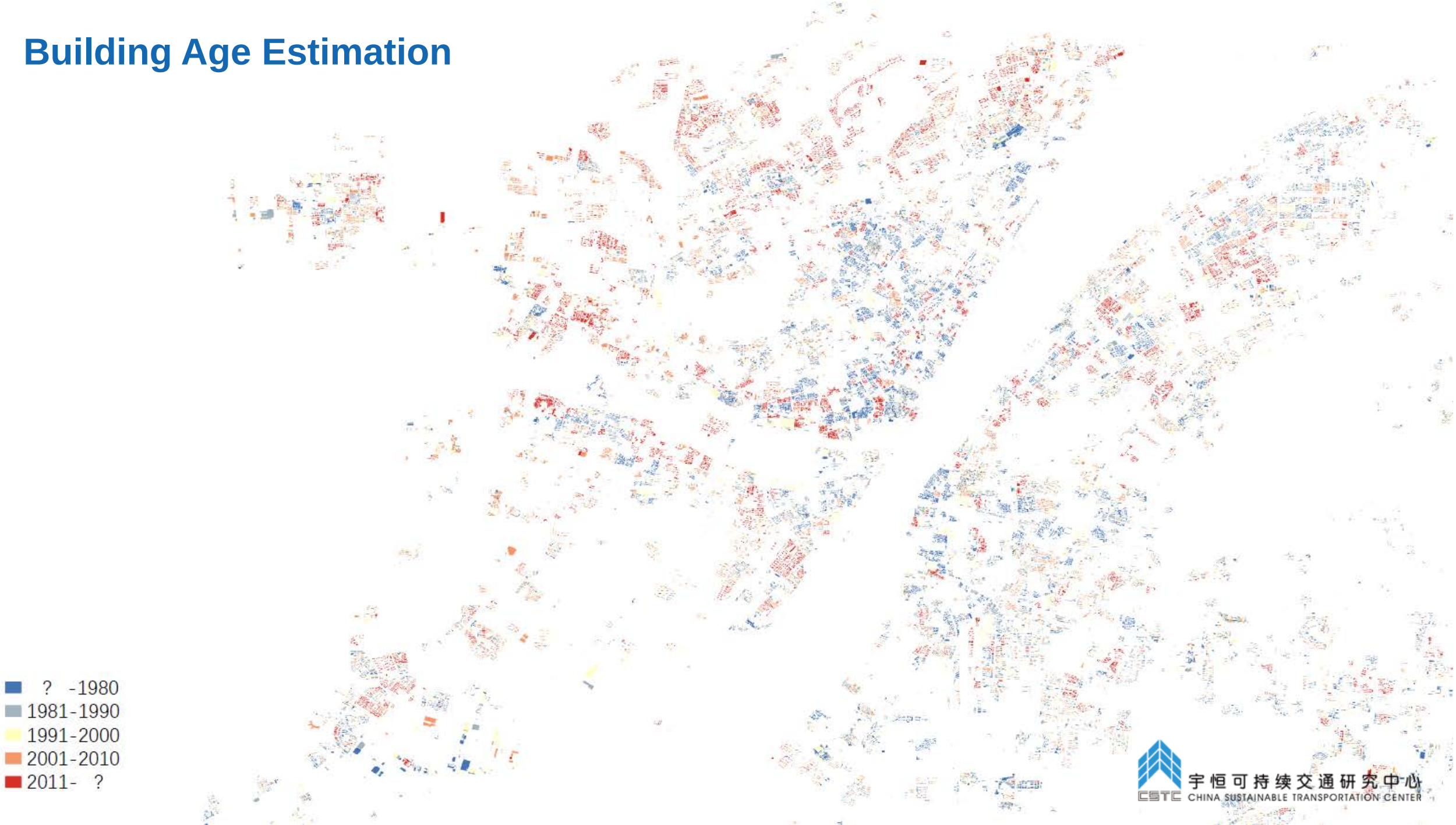
Building Function Classification



Building Age Estimation



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