

Title:	<b>Exploring Synergistic Effect in Metro Station Areas: A Case Study of Shanghai, China</b>
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Subject:	Urban Infrastructure/Transport
Keyword:	Performance Based Design
Publication Date:	2016
Original Publication:	International Journal of High-Rise Buildings Volume 5 Number 2
Paper Type:	<ol style="list-style-type: none"><li>1. Book chapter/Part chapter</li><li>2. <b>Journal paper</b></li><li>3. Conference proceeding</li><li>4. Unpublished conference paper</li><li>5. Magazine article</li><li>6. Unpublished</li></ol>

# Exploring Synergistic Effect in Metro Station Areas: A Case Study of Shanghai, China

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## Abstract

In the process of exploring sustainable development, major cities in China are expanding metro systems as a strategy to reduce the negative environmental and social consequences of fast-paced motorization.

A metro station is not only a transportation node, but also a place where diverse activities can be performed. Therefore, the realization of the spatial potential for human interaction is the essence of the strategy for integrated development in metro station areas. For this paper, 10 well-developed metro stations in Central Shanghai were selected to investigate the correlation between accessibility and spatial performance in station areas. The spatial performance in station areas is significantly affected by metro configuration. However, both vehicle and pedestrian accessibility show weak influence on spatial performance. A synergistic model was then developed to provide quantitative support for transit-oriented development in metro station areas.

**Keywords:** Metro station area, Accessibility, Spatial performance, Synergistic effect

## 1. Introduction

As the fastest-growing economy in the world, China is experiencing a rapid increase in private vehicle ownership, which has led to rising traffic congestion, increased energy consumption, and increased air pollution. These problems obstruct the sustainable development of the national economy.

In the process of exploring sustainable development, transit-oriented development (TOD) has become widely adopted in China (Cervero and Day, 2008; Pan and Ren, 2005; Pan *et al.*, 2011; Thomas and Deakin, 2008). However, most of the TOD performance standards developed in the United States were not directly applicable to China. Zhang (2007) reviewed the literature on the TOD experience, and explored a specifically “Chinese edition of transit-oriented development” derived from the experience of urban development around transit in Hong Kong, Taipei, and Shanghai. More recently, Cervero pointed out that, rapid transit systems like the Shanghai Metro represent the best choice for implementing TOD in China’s high-density cities. In Shanghai at least 24% of the vehicle miles traveled (VMT) could be reduced by using metro system (Cervero, 2011).

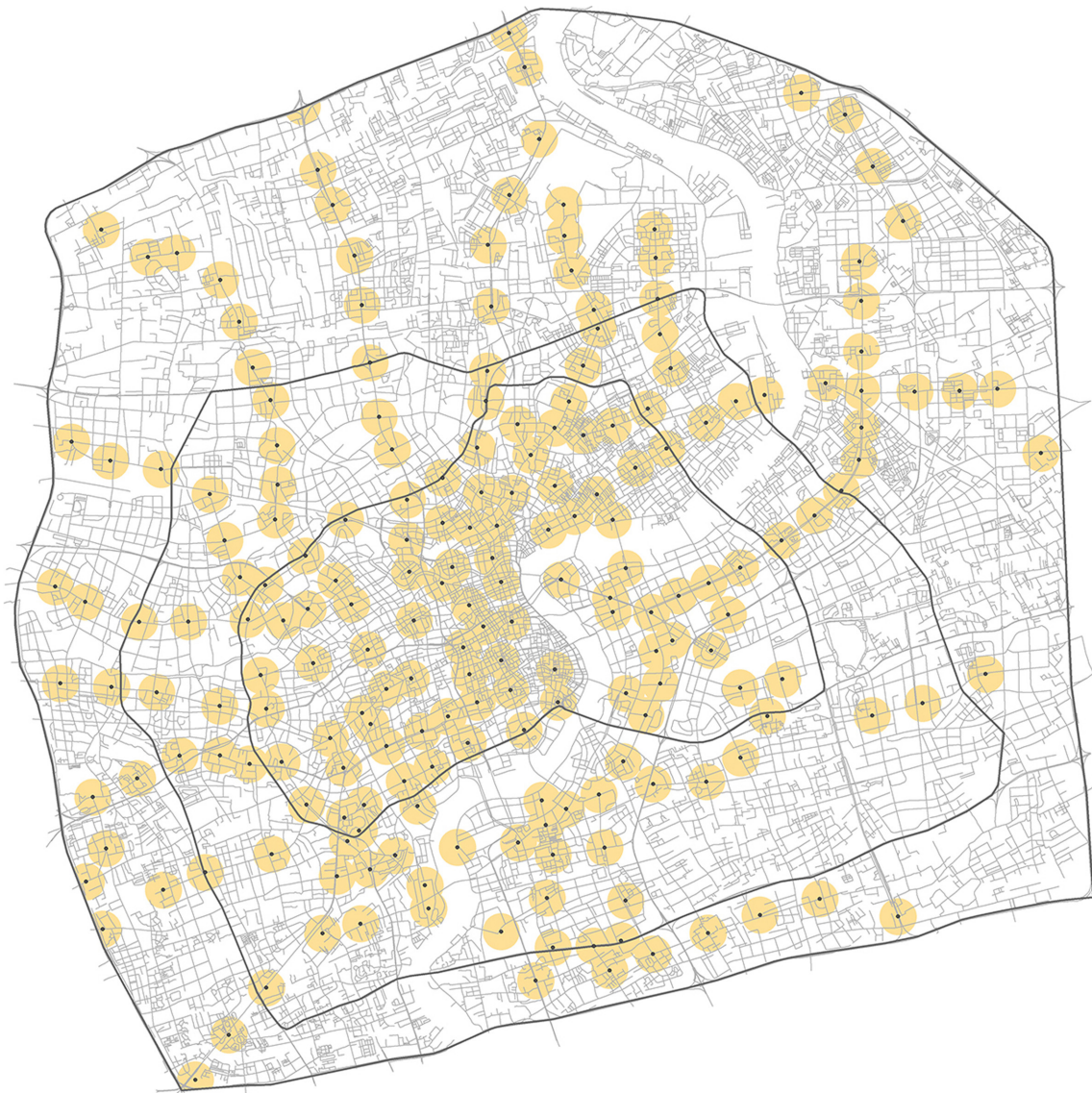
In this context, Major cities in China are building and expanding metro systems as a strategy to reduce the negative environmental and social consequences of fast-paced

motorization. In Shanghai, from the first metro line opened in 1993, to the end of 2014, there were 14 metro lines and 337 stations, with an operating route length of 548 km, making it the longest in the world. The metro service covers 25% of the center of Shanghai, and 51% of the core area (Fig. 1). It is estimated that the Metro network will comprise 18 lines spanning 800 km by the end of 2020. The metro system has radically changed the accessibility pattern of the Shanghai metropolitan area.

Parallel to the TOD tradition in the USA and its adaptation in China, a node-and-place model was developed in Europe for the exploration of the development potential of station areas in an urban region (Bertolini, 1996, 1998, 1999; Bertolini and Spit, 1998; Trip, 2007). According to Bertolini’s theory, the intense and diverse flows of people passing through public transportation nodes have the potential of translating into equally intense and diverse patterns of human interaction. If the right conditions are met, social, cultural and economic activities that require physical proximity can thrive in these areas. This potential can be realized in a relatively sustainable way, as it can be coupled with environmentally more efficient transport, land-use patterns and urban structure and design. A station is not only a transportation node, but also a place where diverse activities can be performed. Therefore, the realization of the potential for physical human interaction is the essence of the strategy for transit-oriented development at and around public transportation nodes.

However, the metro network of Shanghai has expanded too rapidly to integrate the basic transportation function of the stations into urban design. Based on the current

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**Figure 1.** Metro service coverage areas of the center of Shanghai in 2014.

situation, a node-place model was used to investigate the correlation between network accessibility and spatial performance of metro station areas. The purpose of this study is to develop an integrated model between traffic accessibility and spatial usage, so as to provide quantitative support for the design and development of metro station areas.

## 2. Analyses and Investigations

Under the inspiration of L. Bertolini's Node-Place model, the node value was measured by the accessibility of the node, which includes accessibility by different transport modes. The place value was evaluated by spatial performance, which is measured by the intensity and diversity of activities in the area.

### 2.1. Accessibility analysis

#### 2.1.1. Network measures of accessibility

Accessibility is commonly defined as “the potential of opportunities for interaction” (Hansen, 1959), measuring the size of opportunities such as employment, retail floor area, population, retail sales, etc., and inversely moderating this with the distance, travel cost, travel time or other similar spatial metrics variables. For the purpose of identifying the size impact on network configuration in shaping accessibility, we need to use indices of accessibility that are not weighted by land use to begin with.

On network, the first unweighted definition of accessibility can be found in Shimbel (1953). Shimbel defined accessibility on network as the inverse of dispersion which based on the measure of “unweighted mean shortest path length”, and also defined “stress” as “the resulting flow po-

tential of the link,” which measures the number of shortest paths pass through a link. Shimbel’s accessibility and “stress” correspond to “closeness centrality” and “betweenness centrality” in Social Network Analysis. More recently, a number of transport research studies have demonstrated the fruitfulness of such a network-based accessibility approach (Borzachiello *et al.*, 2010; Cutini, 2001; Newman *et al.*, 2006; Porta *et al.*, 2006; Xiao *et al.*, 2013).

### 2.1.2. Data and software

Numerous studies have confirmed that spatial configuration correlates with observed movement flow levels by both pedestrian and vehicle (e.g., Hillier *et al.*, 1987, 1993; Hillier and Iida, 2005; Peponis *et al.*, 1989). In metro station areas, the metro network configuration plays an important role in the movement-generating pattern (Chiaradia *et al.*, 2005; Zhang *et al.*, 2015). Furthermore, Lu’s recent study found that public transport, driving and walking accounted for 81% of all trips in central Shanghai (Lu, 2011). Based on above, unweighted accessibilities of the three major transport modes will be calculated in this study.

Spatial accessibility variables computed using Spatial Design Network Analysis (Chiaradia *et al.*, 2014; Cooper *et al.*, 2014)<sup>1</sup> (SDNA) are used in this study. SDNA is a set of multi-level spatial analysis techniques for urban networks. It calculates centrality closeness and betweenness centrality on networks with user-defined radii with different types of metrics – Euclidean, Angular, and Topological distance – as the travel budget. Least Euclidean metric is the standard shortest distance, and it is often criticized because it does not account for the potential value of speed (which does not apply to walking) and is blind to geometry. The Least Topological metric values the fewest number of direction changes, but is blind to Euclidean change. The Least Angular metric is the smallest accumulated angular change among links, which is associated with capturing both geometric directness and geometry of speed.

The Angular metric has been proven to have a good influence on pedestrian and vehicle flows, and to have exerted other influences on property prices (Chiaradia *et al.*, 2012; Hillier and Iida, 2005). An analysis of street networks in Shanghai according to the three metrics also demonstrated that the Angular metric is a good proxy for Euclidean metric (Zhang *et al.*, 2015). In our study, Angular Betweenness (BtAW) was chosen for measuring how often each link is used on Angular shortest paths from all links to the other links.

### 2.1.3. Accessibility of street network

A number of studies have used 400–600 m as a baseline comfortable walking distance (Calthorpe, 1993; Marc Schlossberg, 2003; NJTransit, 1994). Studies in Shanghai also showed that 500–600 m is a comfortable walking distance (Bian, 2006; Liu, 2012, p. 20; Pan *et al.*, 2007, p. 93). The majority of within-city trips are less than 5 km in Shanghai, and this is also the upper limit of non-motorized trips (Zacharias, 2005).

Street network accessibility (unweighted by land use) at the micro- and macro-spatial scale (radius at 500 m and 5,000 m) are used for explaining the potential flows of walking and car trips in Shanghai. As can be seen on the map (Fig. 2), links with high Betweenness at micro level (radius at 500 m) tend also to be links that are closely clustered, i.e., short streets, small blocks and high junction density. Most of these links are in the core area of Shanghai. At macro level (5,000 m) the main arterial networks that facilitate movement from one part of Shanghai to the others is identified. The arterials are evenly distributed in the whole city.

The metro station area has been defined as the surface included within a “walkable radius” of 500 meters from each metro entrance. Ten well-developed metro station areas in Central Shanghai were selected as samples.<sup>2</sup> Based on this, the street betweenness accessibility of each sample is the average BtAW value of all links inside each station area (Fig. 3).

### 2.1.4. Accessibility of metro network

A topologic network using one link between each two stations was created to represent metro configuration. In this study, the authors follow Chiaradia’s approach (Chiaradia *et al.*, 2005), using two steps to represent each transfer between connecting metro lines. The topologic betweenness of links (Fig. 4(a)) connected to each station were then averaged to get an accessibility value for each station (Fig. 4(b)).

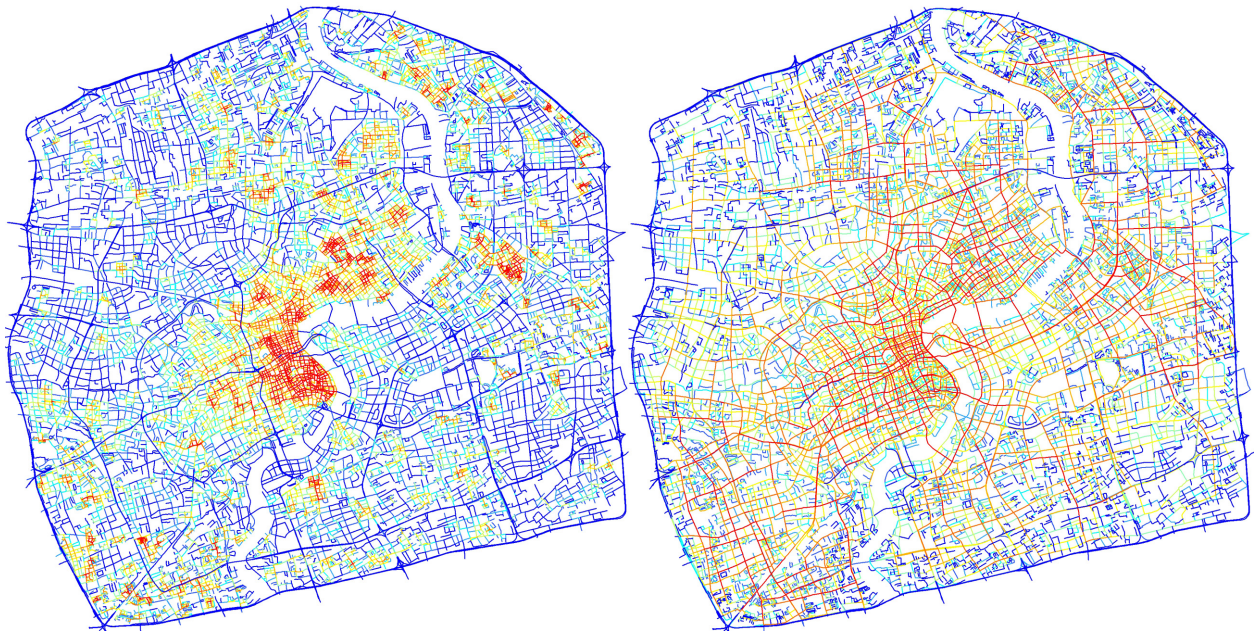
## 2.2. Spatial performance

Under the perspective of urban design, “spatial performance” in this study mainly focused on the spatial usage and user movement. The evaluation of spatial performance is based on the three major functional categories which strongly involved in urban marketing process: commercial, office and residential. The intensity of commercial space, the rental price and occupational saturation rate of office space, the property price and residential density of residential space were chosen to evaluate Place-Value.

<sup>1</sup>SDNA (Spatial Design Network Analysis) is a plugin for ArcGIS, Autocad, and open source GIS (QGIS) it uses the Shapefile (.shp) or .gdb files and link/node standard to analyze the spatial networks design characteristics using centrality measures and other measures such as severance. It provides many control variables. The software is freely available after registration at [www.cardiff.ac.uk/sdna/with full specifications](http://www.cardiff.ac.uk/sdna/with%20full%20specifications).

<sup>2</sup>A. Jiangwan Stadium -Wujiaochang station; B. Zhongshan Park Station; C. East Nanjing Road Station; D. Jing'an Temple Station; E. Shangcheng Road-Dongchang Road Station; F. Xintiandi-Huangpi Road Station; G. Xujiahui Station; H. North Sichuan Road Station; I. Lujiazui Station; J. Dapujiao Station.





**Figure 2.** Betweenness of Shanghai Street network in 2014 (BtAW, radius: 500m, 5000m). From cold color (blue) to warm color (red), the level of accessibility ranked from low to high.

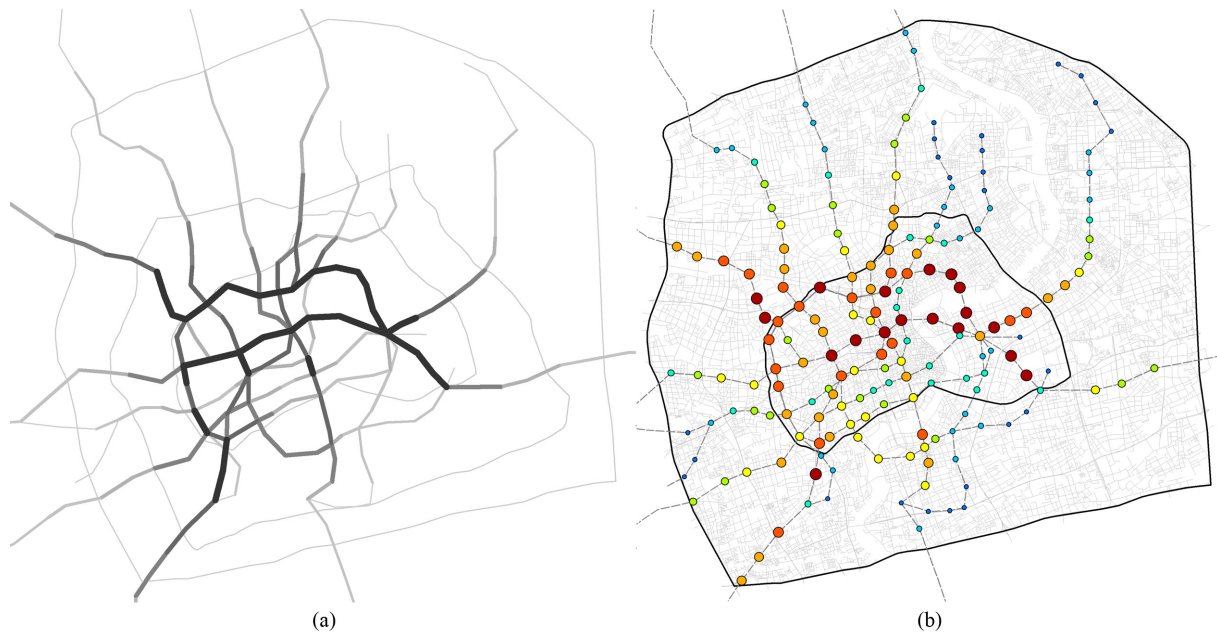


**Figure 3.** Pedestrian Accessibility and Vehicle Accessibility in 10 metro station areas.

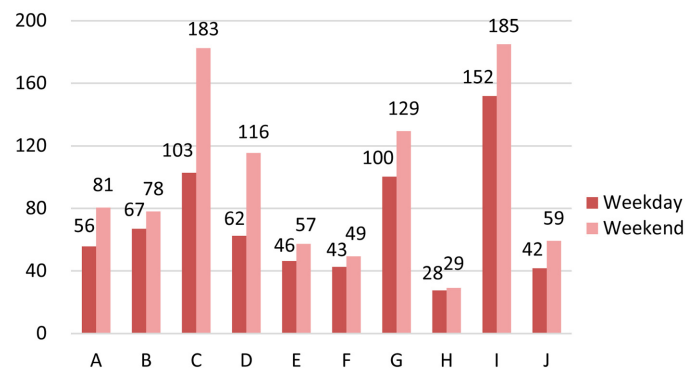
The commercial intensity data in station areas were obtained by using the “Gate Count” method of observation, in which an observer counts all people crossing a notional gate across each survey commercial entrance (Chang and Penn, 1998). These data were respectively gathered at different times of one weekday and one weekend, with each set of observations lasting 3 minutes. The time periods were 8-10 AM, 10-12 AM, 12 noon-2 PM, 3-5 PM, 5-7

PM, 7-9 PM, giving an all-day average commercial intensity data map.

The commercial performance of each sample was calculated as the average intensity data of all commercial spaces inside station area. As is shown in Fig. 5, the commercial spaces perform better on weekends than on weekdays. The commercial performance around East Nanjing Road station, Xujiahui station and Lujiazui station are



**Figure 4.** Topological Betweenness of Metro network and Metro stations in Shanghai.



**Figure 5.** The commercial intensity data in 10 station areas (people per hour).

higher than those around other stations on both weekdays and weekends. The commercial intensity of North Sichuan Road Station area is the lowest of all 10 samples.

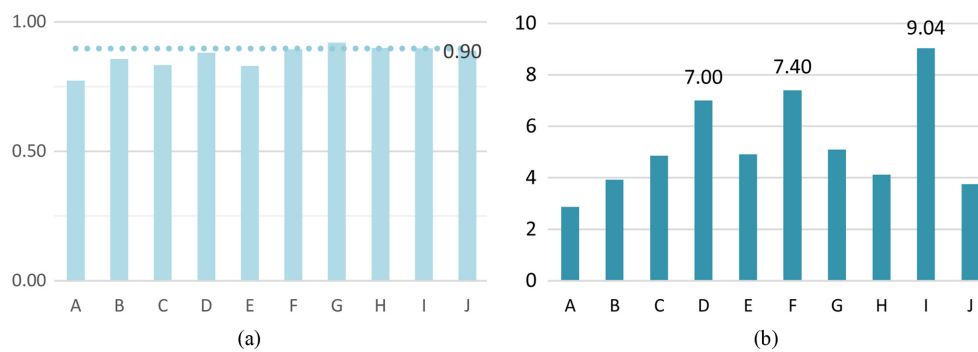
The “Gate Count” method was also used to collect the number of employees for office space. The occupational saturation rate of office space is calculated by dividing saturated employee volume by the number of employees. Most of the office buildings in the 10 samples are classified as Class A grade buildings which are well-maintained, well-secured, and located in a highly accessible area.

Fig. 6(a) shows the saturation rate of office spaces in 10 station areas. The range of Saturation Rate variation among different station areas is very small. This is because the demand for Class A properties exceeds supply in Shanghai, and the saturation rates of Class A properties are close to 100%. Fig. 6(b) shows the Rental Prices of office spaces

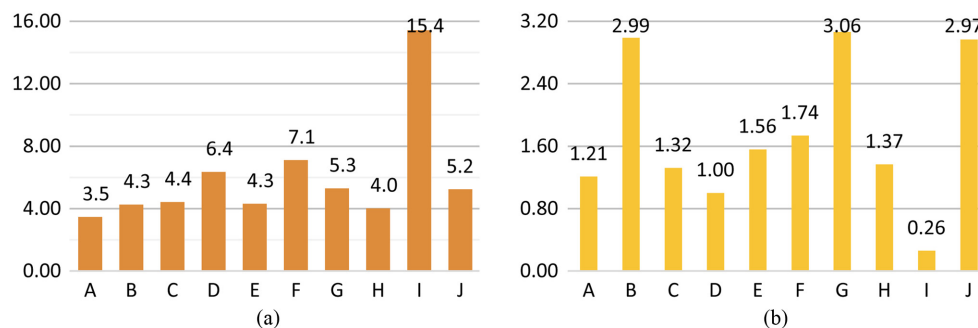
in 10 station areas. Highly significant differences were noted among the samples in mean values of office rentals. It can be easily seen that the highest rental prices are around Lujiazui Station, Jinansi Station, and Xintiandi Station, with rental rates of 9.04, 7.99 and 7.44 yuan per square meter per day respectively.

Tomson Riviera Garden is the only residential district situated within walking distance of central Lujiazui. It is also one of Shanghai’s most expensive apartment buildings, where the sales price is above 150,000 yuan per square meter, contributing to the Lujiazui area’s property prices the highest in Shanghai. The average property price in Jiangwan Stadium-Wujiaochang area is about 35,000 yuan per square meter, relatively lower than those in other station areas (Fig. 7(a)).

As for the residential density (Fig. 7(b)), the Lujiazui



**Figure 6.** Office performance in 10 station areas: (a) Saturation Rate, (b) Rental Prices (yuan per square meter).



**Figure 7.** Residential performance in 10 station areas: (a) average Property Price (10,000 yuan per square meter), (b) the residential density (people per 100 square meters).

area is the lowest in 10 samples, only 0.26 person per 100 square meters. The residential density of Xujiahui area, Zhongshan Park area and Dapujiao area are respectively 3.06, 2.99, 2.97 person per 100 square meters, far exceeding those of elsewhere.

### 2.3. Correlation analysis

A correlation analysis was performed in order to investigate the relationship between accessibility and spatial performance. As Table 1 shows, the commercial performance in station area is strongly affected by metro accessibility. The  $r$ -square is 0.552. However, both vehicle and pedestrian accessibility show weak influence on commercial performance. The significant positive correlation between

commercial intensity and metro accessibility is due to the fact that higher metro accessibility will produce more people flows and therefore, more consumers.

Table 1 also shows a significant correlation between metro configuration and office rental price ( $r^2=0.589$ ), although the correlations between metro accessibility and office occupational saturation rate is low.

For residential space, the metro configuration strongly affects property price ( $r^2=0.440$ ), while its correlation with residential density is weak. The reason for the high correlation between metro accessibility and property price is that the metro network largely satisfies the commuting demand produced by residential districts.

**Table 1.** R-square values for correlations between the spatial performance and accessibility of 10 metro station areas

	Metro Accessibility (Mean BtCn)	Vehicle Accessibility (BtA5000)	Pedestrian Accessibility (BtA500)
Commercial Intensity	0.552*	0.037	0.002
Office Rental Price	0.589**	0.0008	0.022
Office Occupational Saturation Rate	0.220	0.022	0.0007
Residential Property Price	0.440*	0.022	0.018
Residential Density	0.049	0.028	0.047

\*Correlation is significant at the 0.05 level.

\*\*Correlation is significant at the 0.01 level.



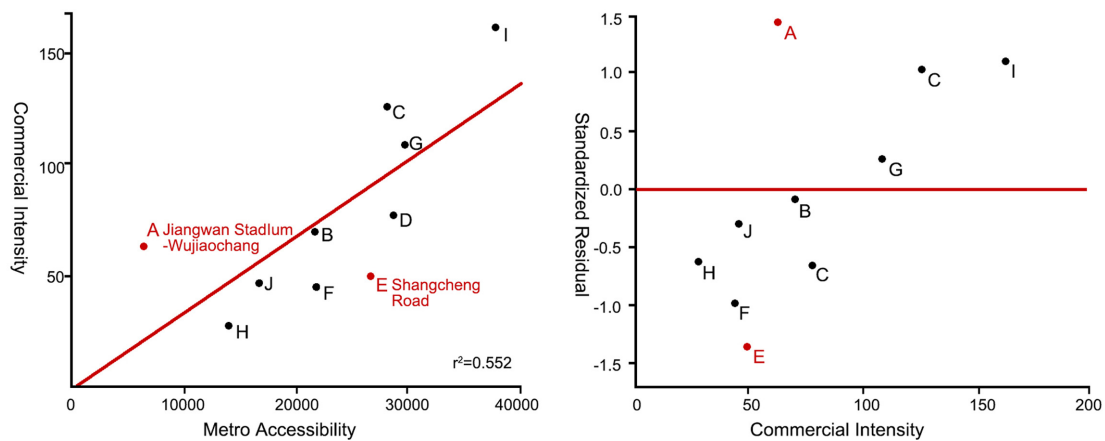


Figure 8. Correlation of metro accessibility and commercial performance: Linear regression and residual.

### 3. Integrated Analysis Model

#### 3.1. Synergistic analysis of accessibility & spatial performance

Based on the above analysis, we can see that the metro network is the only significant configuration variable that affects spatial performance among different modes of transport. Linear regression can be used to illustrate the node-place effect in metro station areas. The node index is a measure of metro accessibility, and the place index is measured by the spatial performance of different functions.

Wujiaochang station is the only station situated outside Inner Ring road. The station didn't open until April 2010, and its metro accessibility is relatively lower. The Wujiaochang commercial center has developed rapidly since it became a new municipal commercial sub-center of Shanghai in 2002. This area had a gross commercial floor area of 750,000m<sup>2</sup> at the end of 2010, and has since attracted many commercial tenants. Not surprisingly, the Jiangwan Stadium-Wujiaochang area can be identified as an “unsus-

tained commercial place.” As can be seen in Fig. 8, the commercial activities are relatively more developed than transportation services in this area. Conversely, the Shangcheng Road-Dongchang Road area is an “unsustained commercial node,” where transport development is high, but the commercial performance is poor.

The official saturation rate of the Jiangwan Stadium-Wujiaochang area is the lowest in 10 areas, making it one of the “unsustained official nodes.” The situations in East Nanjing Road area and Shangcheng Road-Dongchang Road area are similar. This may be partially explained by the following two reasons.

On one hand, there are high proportions of Class B properties in these three areas, respectively accounting for 25%, 29% and 35% of the total. On the other hand, these metro stations have been operating for less than 5 years; there was a time lag for metro accessibility affecting spatial usage.

The Xintiandi-South Huangpi Road area is located in the luwan District of center Shanghai, where office facili-

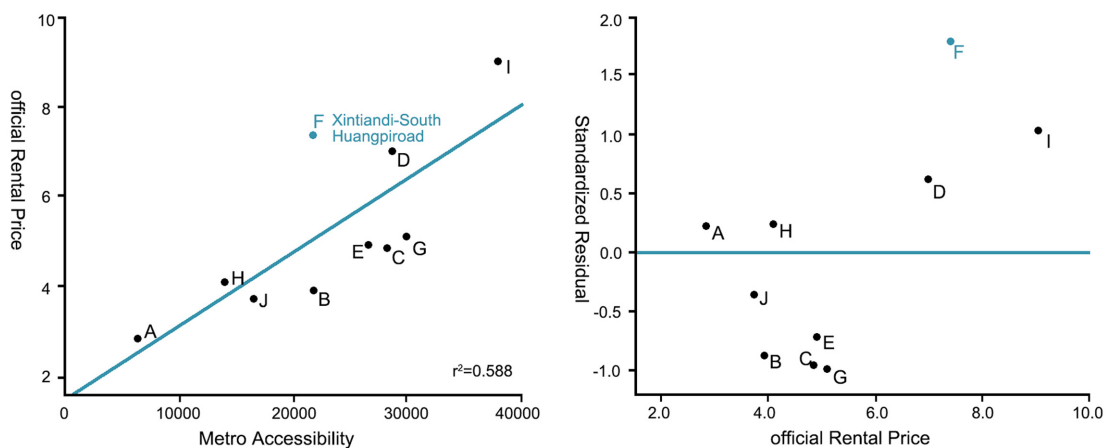
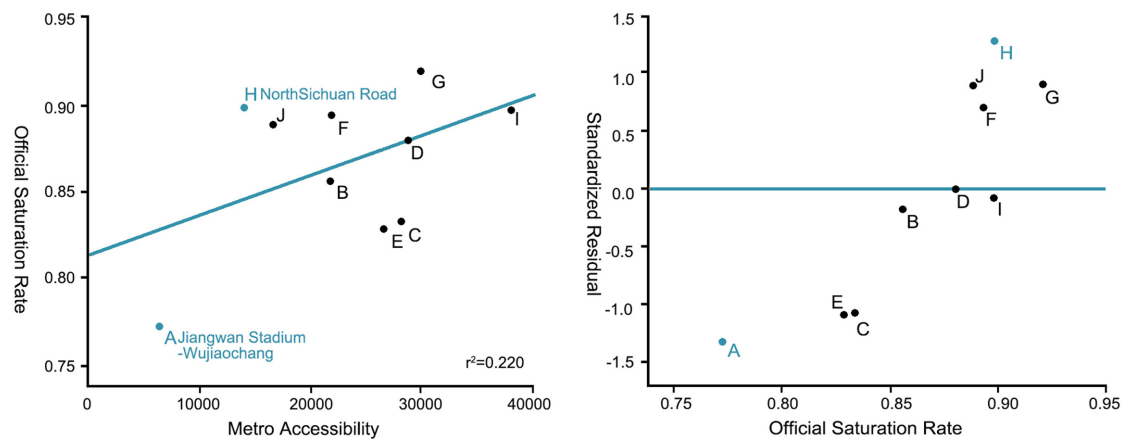


Figure 9. Correlation of metro accessibility and official Saturation Rate: Liner regression and Residual.





**Figure 10.** Correlation of metro accessibility and official Rental Price: Liner regression and Residual.

ties are relatively much more developed than transportation services. Real estate prices and office rental rates increased rapidly after the Taipingqiao urban renewal project was completed. Office towers in this area aim for the top end of the market, as does the overall brand effect of Xintiandi. At Shui On Plaza, for example, is one of Shanghai's most prestigious office buildings. It has been one of the most expensive and highest-occupancy buildings since its completion in early 1997.

For most of the residential quarters, the property prices have good correlation with metro accessibility. But the metro is not always the first choice of transportation for residents, especially in exclusive residential districts. The Lujiazui area is a typical example. In Lujiazui, residential prices are high, but the metro accessibility is low, making this area an “unsustained residential place.”

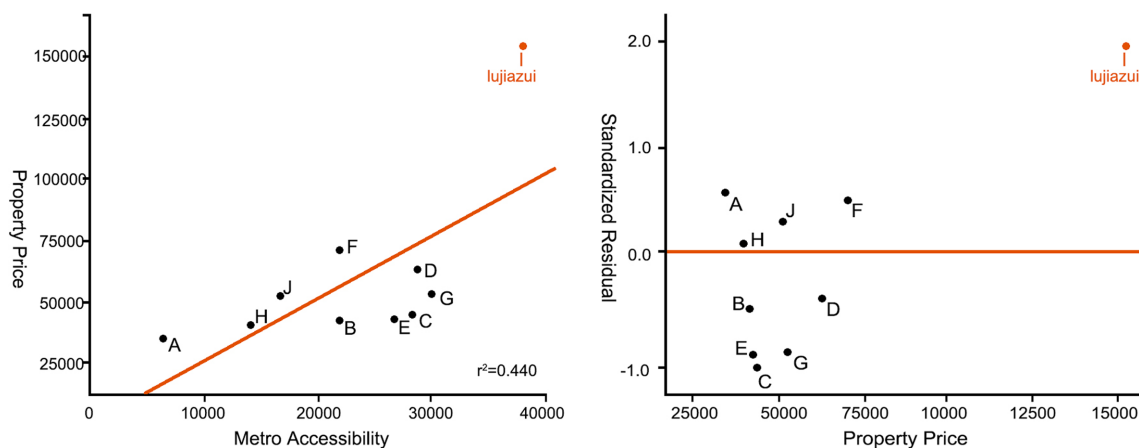
### 3.2. Summative score of spatial performance

Principal component analysis was used to reduce the number of spatial performance variables. All of the spatial

performance variables, including commercial intensity, office rental price, office occupational saturation rate, residential property price and residential density, were entered into a principal component analysis to reduce the number of spatial performance variables.

To ensure proper application of this technique, the authors inspected KMO measure, and Bartlett's test of sphericity, which indicated that spatial performance variables are adequate for a principal component analysis. Table 2 shows that the first two components cumulatively account for 84% of the original variables.

To get the percent of variance in all the variables accounted for by each factor, divide the values in Component Matrix (Table 3) by the square root of the corresponding eigenvalue. So the variance percent of component 1 divides 2.930 by (0.736, 0.930, 0.609, 0.944, -0.512), producing (0.430, 0.543, 0.356, 0.551, -0.299); similarly, the variance percent of component 2 divides 1.249 by (-0.132, 0.088, 0.758, -0.036, 0.805), producing (-0.110, 0.079, 0.678, -0.032, 0.720).



**Figure 11.** Correlation of metro accessibility and property price: Linear regression and residual.

**Table 2.** Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Square Loadings		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1	2.930	58.599	58.599	2.930	58.599	58.599
2	1.249	24.988	83.587	1.249	24.988	83.587
3	.566	11.313	94.900			
4	.152	3.042	97.942			
5	.103	2.058	100.000			

Extraction Method: Principal Component Analysis.

**Table 3.** Component Matrix

	Component	
	1	2
Commercial Intensity (C)	.736	-.132
Office Rental Price (O <sub>1</sub> )	.930	.088
Office Occupational Saturation Rate (O <sub>2</sub> )	.609	.758
Residential Property Price (R <sub>1</sub> )	.944	-.036
Residential Density (R <sub>2</sub> )	-.512	.805

Multiply the percent of variance by corresponding standardized variables to calculate the principal components:

$$\text{Factor 1} = 0.430 * C + 0.543 * O_1 + 0.356 * O_2 + 0.551 * R_1 - 0.299 * R_2$$

$$\text{Factor 2} = -0.110 * C + 0.079 * ZO_1 + 0.678 * O_2 - 0.032 * R_1 + 0.720 * R_2$$

A summative score to evaluate spatial performance can be obtained according to the components and component loadings for each sample (formula 1).

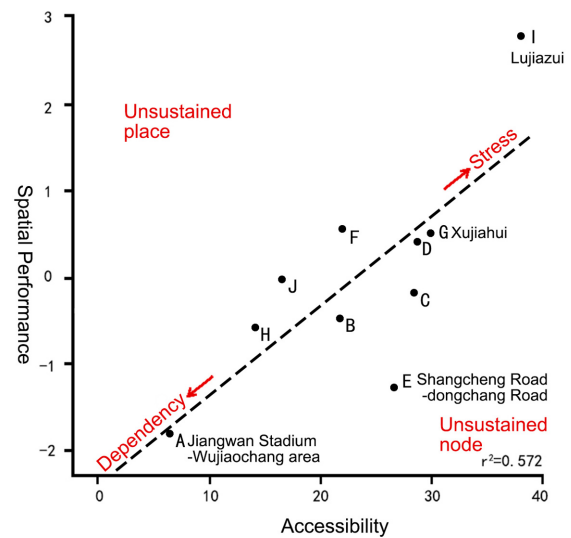
summative score =

$$\frac{2.930}{2.930+1.249} \times \text{Factor 1} + \frac{1.249}{2.930+1.249} \times \text{Factor 2} \quad (1)$$

### 3.3. Synergistic model

The KMO measure of accessibility variables was 0.430, which indicated that principal component analysis is inappropriate. Accordingly, a stepwise multiple regression analysis was taken to find out the effect of accessibilities on spatial performance. In three independent accessibility variables, metro accessibility is the only one entered into the model. The r-square value was 0.572 (Table 4), which shows that the spatial performance is mainly affected by metro network.

A synergistic model was developed to provide quantitative support for transit-oriented development in metro



**Figure 12.** Integrated model between traffic accessibility and spatial usage. A. Jiangwan Stadium -Wujiaochang station; B. Zhongshan Park Station; C. East Nanjing Road Station; D. Jing'an Temple Road Station; E. Shangcheng Road-dongchang Road Station; F. Xintiandi-Huangpi Road Station; G. Xujiahui Station; H. North Sichuan Road Station; I. Lujiazui Station; J. Dapugiao Stati.

station areas. The node value is measured by metro accessibility, and the place value is measured by summative spatial performance. As shows, four ideal-typical situations can be distinguished. Along the middle diagonal line are balance areas where the node and the place are equally strong. Among those areas, Xujiahui is at the top of the middle line. It is an “under stress” area, where the potential for physical human interaction is highest (strong node) and has been realized (strong place). Jiangwan Stadium-Wujiaochang area is a “dependent” area at the bottom of the middle line. This indicates that space potential is minimal here, but the demand for traffic accessibility is also low.

**Table 4.** Model Summary<sup>b</sup>

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.756 <sup>a</sup>	0.572	0.518	0.865

<sup>a</sup>Predictors: (Constant), Metro Accessibility.

<sup>b</sup>Dependent Variable: Spatial Performance Summative Score.

Finally, two “unbalanced” situations can be identified. On one side, at the top left of the middle line is the Lujiazui area, where urban activities are relatively much more developed than transportation accessibility. Lujiazui station was put into operation in 2000, but this area became an “unsustained place,” due to its large-scale real estate development in the last 15 years. On the other side, the Shangcheng Road-Dongchang Road area is an “unsustained node”. There are two large office building projects under construction in this area, and the commercial development between two stations was obviously obstructed by Century Avenue. Therefore the place value is relatively lower than the node value.

#### 4. Discussion

According to the above integrated model, in old urban areas, modifying traffic accessibility is an appropriate way to balance “node” and “place” value. In Lujiazui, the traffic situation will be improved after a new metro line (line 14) opens in 2020. However, it is usually difficult to adjust transport network after the implementation of city planning, not to mention the long time lag. Therefore, optimizing function allocation is an easier and more immediate way to balance the “node” and “place” values in existing urban areas.

In the development of a new urban area, the synchronization of traffic and spatial design is the key point, thus the following principles should be considered for integrated development in metro station areas in the early planning stage: 1) Allocate facilities according to traffic accessibility, 2) Design with a mixed-use function to avoid peak-hour traffic patterns, 3) Balance spatial volume and traffic accessibility, 4) Arrange function distribution and optimize spatial performance based on metro accessibility.

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