Jobs–Housing Balance of Bus Commuters in Beijing

Exploration with Large-Scale Synthesized Smart Card Data

Jiangping Zhou and Ying Long

Jobs–housing studies have rarely used smart card data provided by public transportation agencies or focused on bus commuters. In this study, massive smart card data were used to estimate 216,844 bus commuters' workplace and residence locations in Beijing. These data enabled a jobs–housing study of bus commuters in the metropolis with a much larger sample size than in most other studies. The study found that Beijing's bus commuters had a shorter actual required commute (ARC) and a shorter minimum required commute (MRC) than commuters in four other auto-dependent Western cities with comparable population and land use size. The study also indicated that Beijing's bus commuters had a longer ARC and a longer MRC than commuters of all modes in Guangzhou, a metropolis in southern China half the size of Beijing. Consultations with local experts, field surveys, and information provided by online housing search engines were used to supplement the smart card data. The study established five land use prototypes of jobs–housing imbalance and proposed countermeasures to address the imbalance.

Car dependence, traffic congestion, long commutes, and associated air pollution and greenhouse gas emissions have become notable phenomena that characterize many populous cities. Planners, policy analysts, and public agencies have advocated or even incentivized jobs–housing balance as a way to reduce peak period travel and optimize commutes, in particular, commutes by driving alone (*1–6*). Not surprisingly, various factors contribute to jobs–housing balance or imbalance among social groups in various locales. In the United States, for instance, suburbanization of jobs, housing segregation, inefficient public transportation services, race, and automobile mismatch may all more or less contribute to jobs–housing imbalance (or spatial mismatch) for low-income minorities and new immigrants (*7–10*). In China, the disappearance of work unit (Danwei) compounds and the introduction of the commercial housing market have led to the increasing jobs–housing imbalance of workers in large cities such as Beijing and Guangzhou (*11–15*).

A large body of literature has focused on jobs–housing balance and related topics such as excess commuting and commuting efficiency. Horner (*16*) and Ma and Banister (*17*), for instance, have provided a good review of such literature in the Western context. Many studies of jobs–housing balance have dealt with total commuting flow and treated workers and jobs or the workplace as homogeneous (*18*). This is especially true of two seminal studies (*19, 20*) and others that have extended the two studies in different contexts (*4, 21–23*). To increase the policy relevance of research on jobs–housing imbalance, researchers have paid attention to worker, workplace, and employer heterogeneity. Crane (*24*), Gordon et al. (*25*), and Kim (*26*) have shown that employees can be owners or renters and this status affects their commuting distance, that is, jobs–housing balance. Although not directly dealing with jobs–housing balance, Kwan found that individual and household activity schedules and time budgets are critically important for influencing people's spheres of activity (*27*). Giuliano and Small studied jobs–housing balance among workers in various occupations and found that service workers have the shortest average commutes (*28*).

However, few researchers have looked at the jobs–housing balance of commuters by mode, that is, mode choice heterogeneity. This gap in the literature may have occurred for three reasons. First, conducting and processing surveys to obtain reliable information about individual-level jobs–housing balance and mode choice has not been cheap and has become increasingly expensive. In the United States, for instance, the cost of obtaining this information was $195 per household in 1995 and $411 per household in 2001 (based on a letter from the Committee to Review the Bureau of Transportation Statistics' Survey Programs, to Ashisen Sen, U.S. Bureau of Transportation Statistics, on June 18, 2002, which is available at http://onlinepubs.trb.org/onlinepubs/reports/nhts.pdf).

Second, driving is the dominant commute mode in most developed countries and thus comparatively more attention has been given to the jobs–housing balance of driving commuters in these countries, where most relevant studies have been conducted. Third, although commuters who use different mode choices could face different degrees of jobs–housing imbalance (*7*), little research has been done on the causes and implications of these differences. In developing countries such as China, the study of jobs–housing balance of bus commuters is still quite relevant. A significant percentage (tens of millions) of residents commutes by bus, even in leading cities. In Beijing, for instance, more than five million, or 28%, of the residents commuted by bus as of 2010 (based on the 2011 annual report of Beijing's Transportation Development, in Chinese, internally circulated report, Beijing Transportation Research Center).

Given the large volume of bus commuters, there is a need to study the jobs–housing balance of bus commuters in developing countries. This study used smart card data processed by the Beijing Institute of City Planning to investigate the characteristics of the jobs–housing balance of bus commuters in Beijing. The study adopted the concepts

J. Zhou, Department of Community and Regional Planning, Iowa State University, 146 College of Design, Ames, IA 50011. Y. Long, Beijing Urban Planning and Design Institute, 60 Nanlishi Road, Xicheng, Beijing 100045, China. Corresponding author: J. Zhou, zjp@iastate.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2418, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 1–10.
DOI: 10.3141/2418-01

of excess commuting, minimum and maximum required commutes, and commuting efficiency to estimate the amount of excess commuting of these commuters and the efficiency of their commutes. The study also compared its findings with those of other studies whenever possible. The study contributes to the research on jobs–housing in three dimensions. First, the study specifically dealt with bus commuters, a subgroup of commuters that has rarely been studied. Second, the study used commuter data for a sample size of 216,884, which was much larger than the samples in most other studies. Third, the study explored a new way to synthesize widely available smart card data in the public transportation sector and other publicly available supplementary data and information to establish land use prototypes of the jobs–housing imbalance so as to propose better countermeasures.

This paper provides a survey of the relevant literature, an overview of the city case study, and a description of how the sample of 216,884 was extracted from the smart card data. The study empirically estimated the excess commuting, minimum and maximum required commutes, and commuting efficiency of the sample. The findings were based on the empirical evidence and prototypes of areas suffering severe jobs–housing imbalance in Beijing. The paper concludes with a discussion of directions for further research.

RELEVANT LITERATURE

The jobs–housing balance describes the relationship of the total numbers of jobs and housing units within a given geographical area or within a given travel distance or travel time (*3, 4, 29, 30*). Under the strong assumptions that all jobs, workers, and housing units are homogeneous and workers can switch jobs or housing at little or no cost, analysts have shown that there is a minimum required commute (MRC) for all workers (*19, 20*). But the actual required commute (ARC) for all workers is always larger than the MRC. The difference between MRC and ARC is called wasteful commute (*19*) or excess commuting (*17, 18, 23, 31–41*).

On the basis of the concepts of ARC and MRC, Horner proposed a way to evaluate the commuting efficiency of various cities (*23*). Horner pointed out that in addition to MRC, there is a maximum required commute (MaxRC). The following two ratios can be employed to compare commuting efficiency or jobs–housing balance across cities:

$$E = \left(\frac{\text{ARC} - \text{MRC}}{\text{ARC}}\right)100 \tag{1}$$

$$C_u = \left(\frac{\text{ARC} - \text{MRC}}{\text{MaxRC} - \text{ARC}}\right)100 \tag{2}$$

where E is the amount of excess commuting or how good the jobs–housing balance is in a city and C_u is how much of a city's commute potential has been used.

The smaller C_u is, the more efficient the commute or the better the jobs–housing balance is.

Horner used 1990 U.S. Census data to compare the commuting efficiency of 26 U.S. cities (*23*). Like most of the studies highlighted in Ma and Banister (*17*), Horner's comparisons did not differentiate commuters by mode choice. Thus, it cannot be concluded from these studies whether bus commuters' jobs–housing balance is better or worse than that of other commuters. But when the mode choice of commuters is considered, there tends to be more relevant insight. Levinson, for instance, found that accessibility to jobs and housing has a negative relationship with distance and that transit commuters appear to have greater accessibility than automobile users (*42*). In another study, Cervero found that the low density, single use, and nonintegrated features of many U.S. suburban employment centers have contributed to auto dependence (*43*). The emergence of suburban employment centers with high densities, rich mixtures of land use, and nearby affordable housing (that is, better jobs–housing balance) would increase public transit efficiency and usage as well as mitigate congestion over the long run.

Cervero and Duncan (*44*) and Kockelman (*45*) used microdata from travel diaries and regressed individual or household vehicle miles traveled (VMT) on land use measures (including jobs–housing balance metrics) plus variables that control for household income and survey respondent gender, age, and ethnicity, among other demographic characteristics. These studies were more sophisticated than studies that used data aggregated to census tracts or other geographic areas (*23, 30, 46*). The studies showed how jobs–housing imbalance could partially contribute to auto dependence and higher VMT.

Largely built on the above work and many other studies, Horner and Mefford developed a conceptual approach synthesizing research on spatial mismatch and jobs–housing balance, including disaggregation studies of the phenomena by mode of transportation, within the broader excess commuting framework (*7*). Horner and Mefford used residential and workplace location data from Atlanta, Georgia, and showed that (*a*) the home–work alternatives of minorities (after controlling mode of travel) are more spatially constrained and (*b*) race and mode choice should be simultaneously considered when studying jobs–housing balance.

Murphy studied the extent of mode-based excess commuting in Dublin, Ireland (*38*). Murphy found that excess commuting is considerably greater for drivers. In other words, there is greater commute inefficiency and worse jobs–housing balance associated with driving.

In addition to the above studies on the jobs–housing balance in the Western context, parallel studies have been done on the Chinese context. Based on the travel survey data of a small sample of workers ($n \leq 750$) in Beijing, Wang and Chai (*11*) and Zhao et al. (*14*) found the following:

1. The traditional employer-provided housing system in China contributed to a better jobs–housing balance and a shorter commute.
2. The marketization of the housing supply in China has decreased the jobs–housing balance and lengthened workers' commutes.

Largely because of urban expansion and the suburbanization of affordable housing, all commuters on average have seen an increase in their commuting distance in selected cities such as Beijing (*15, 47–51*). But again, few studies of jobs–housing balance in the Chinese context have focused on bus commuters. One of the studies by Li and Li focused on the jobs–housing balance in two affordable housing projects in Beijing and found that bus commuters' commuting time was greater than that of auto commuters (*47*).

CASE CITY AND DATA

The capital of China, Beijing, has more than 20 million residents and is becoming one of the most populous cities in the world. The land size of Beijing's metropolitan area is 16,410 km^2, making it one of the largest cities in China. Beijing Public Transportation

Company, a state-owned company, provides public bus service in the metropolitan area. As of 2011, the company had 28,343 buses on 948 bus routes with a total length of 187,500 km. In 2011, the buses produced 1.7 billion km of VMT and transported 4.9 billion passengers (information based on http://www.bjbus.com/home/view_content.php?uSec=00000002&uSub=00000012, accessed July 1, 2012).

As of 2005, over 90% of bus riders in Beijing swiped an anonymous smart card when boarding and alighting (for suburban routes) or when boarding (for inner-city routes) to pay the bus fare. The swipes automatically generated the following information on cardholders:

1. Bus trip origin and destination information,
2. Boarding and alighting time, and
3. Unique card number and card type (student card at a discount or regular card).

The information from the smart cards is instantly sent to and stored on a central server. For this study, a whole week's data were requested from the server administrator. The data that were provided contained 77,976,010 bus trips from 8,549,072 nondistinct cardholder records from April 7 to 13, 2008. To identify a cardholder's workplace, one day of data were queried on an MS SQL server; this was repeated for seven days based on the following rules:

1. The card type is not a student card;
2. $D_j \geq 6$ h, where D_k is the duration that a cardholder stays at place j, which is associated with all bus stops within 500 m of one another; and
3. $j <> 1$, which means that j is not the first place in a weekday that the server records.

The most frequently identified workplace of a cardholder in seven days was defined as the final workplace of the cardholder in this study.

From the data queries, it was deduced that a place would be a cardholder's home if the data met the following conditions:

1. The cardholder has an identified workplace.
2. The card type is not a student card.
3. $D_h \geq 6$ h, where D_k is the duration that a cardholder stays at place h, which is associated with all bus stops within 500 m of one another.
4. $F_h \geq F_j$, where F_h is the first most frequent place a cardholder starts a bus trip on a weekday and F_j is the trip frequency to or from j that the cardholder has.

On the basis of those rules or conditions, it was successfully found that there were 216,844 distinct cardholders or workers commuting by bus in Beijing. (Technical details about how the data were obtained can be found in Long and Thill (*52*).) The cardholders' home and workplace were then geocoded and aggregated by traffic analysis zone (TAZ). In Beijing, following conventional rules for defining TAZ boundaries, the local planning agency divided the metropolitan area into 1,118 TAZs. Figure 1 is a map of these TAZs and Tiananmen Square, the center of Beijing.

It was found that the 216,844 cardholders (workers) resided in 729 distinct TAZs and worked in 752 distinct TAZs. Based on this information, matrices were constructed of the commuting trips (M_t) as well as journey-to-work distances (M_d) for this study. To be consistent with the distances used in other studies so that apple-to-apple comparisons could be made, the distances in M_d were linear distances between centroids of TAZs for trips between two different TAZs. For trips within the same TAZ, the distance equals R_i, where $R_i = \sqrt{A_i/\pi}$ and A_i is the area of TAZ_i. Portions of M_t and M_d are shown in Tables 1 and 2.

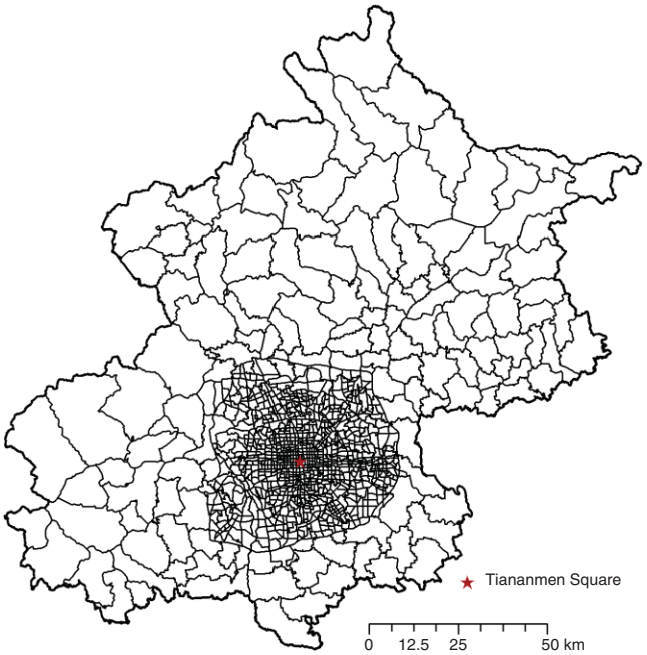

FIGURE 1 1,118 TAZs in Beijing.

EMPIRICAL ANALYSIS

ARC of the Commuters

The following formula was used to obtain the ARC of the 216,844 bus commuters in Beijing:

$$\text{ARC} = \sum_h \sum_j \frac{t_{hj} * d_{hj}}{T}$$

TABLE 1 Portion of M_t

	TAZ_j						
TAZ_h	1	2	3	4	5	. . .	752
1	120	0	0	0	1	. . .	. . .
2	80	1	0	0	0	. . .	. . .
3	10	0	0	0	0	. . .	. . .
4	3	0	7	0	0	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
729	. . .	. . .	. . .	. . .	. . .	. . .	. . .

NOTE: Ellipsis points indicate the omission of numbers.

TABLE 2 Portion of M_d

	TAZ_j						
TAZ_h	1	2	3	4	5	. . .	752
1	0.03	0.44	0.47	0.42	0.58	. . .	. . .
2	1.53	0.04	0.95	1.85	1.92	. . .	. . .
3	1.87	0.95	0.1	0.90	1.08	. . .	. . .
4	2.92	1.92	1.08	0.06	0.42	. . .	. . .
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
729	. . .	. . .	. . .	. . .	. . .	. . .	. . .

where

t_{hj} = number of commuters from TAZ_h (home) to TAZ_j (workplace),
d_{hj} = distance between TAZ_h and TAZ_j, and
T = total number of bus commuters.

MRC and MaxRC of Commuters

For the MRC and MaxRC calculations, the standard linear programming method was employed. The calculations for solving the optimization problems were as follows:

$$\min \frac{1}{T} * \left(\sum_h \sum_j t_{hj} * d_{hj} \right) \quad \text{or} \quad \max \frac{1}{T} * \left(\sum_h \sum_j t_{hj} * d_{hj} \right)$$

subject to

$$\sum_j t_{hj} = O_h$$

$$\sum_h t_{hj} = D_j$$

$$t_{hj} \geq 0$$

where O_h is the total number of commuters living in TAZ_h and D_j is the total number of commuters working at TAZ_j.

E and C_u

After ARC, MRC, and MaxRC were obtained, E and C_u were calculated from Equations 1 and 2.

Results

Table 3 presents the ARC, MRC, MaxRC, E, and C_u of Beijing bus commuters as well as relevant results that were identified from selected studies.

Table 3 shows that first, thanks to the processed smart card data, this study was able to have the largest sample size among all similar studies identified. Bus commuters in Beijing have a shorter ARC or MRC than commuters of all modes in four other cities (Los Angeles, Atlanta, London, and Toronto) of comparable land size and population size. It was surprising that the ARC and MRC of bus commuters in Beijing were larger than those of all commuters in Guangzhou, another populous city in the southern part of China. But given that the land size of Guangzhou (about 7,400 km^2) is only about half that of Beijing, the finding is probably understandable.

Second, disregarding time and sample selection issues, in-vehicle commuting time based on the processed smart card data was less than total commuting time from travel surveys of bus commuters in Beijing across the six studies and surveys highlighted in the table. This finding indicates that (*a*) smart card data do provide accurate estimates of in-vehicle commuting time and (*b*) the in-vehicle commuting time could be used to cross-check the reliability of self-stated total travel time given by travel surveys. For instance, self-stated travel time should be greater than in-vehicle travel time since most commuters would have to spend time completing home-bus stop and bus stop-workplace trips.

Third, the percentage of excess or wasteful commute time for bus commuters in Beijing (64%) is notably higher than that of most of the other cities. The percentage of excess or wasteful commute time for bus commuters in Beijing is comparable to that for all commuters in Philadelphia (67%, reported in Horner (*23*)) and in Toronto (65%). Domestically, the percentage of excess or wasteful commute time of bus commuters in Beijing is greater than that of commuters of all modes in Guangzhou. All the above comparisons between Beijing and other cities, as a whole, indicate that bus commuters in Beijing have noticeable jobs–housing imbalance.

Fourth, the C_u value of Beijing bus commuters is the lowest among all values presented in the table. This finding indicates that the jobs–housing imbalance of bus commuters in Beijing could potentially get worse. The commuting time differences between two local surveys in 2005 and 2010 have reflected this trend.

DISCUSSION OF RESULTS

Commuting Efficiency for Bus Commuters

The above analyses have shown that bus commuters in Beijing face a significant level of excess or wasteful commute time. Two questions naturally arise from this finding:

1. What caused the high level of excess or wasteful commute time?
2. What can be done about it?

With only the smart card data, it is impossible to provide convincing answers to these questions. But extra processing of the smart card data could offer some clues. Based on M_d and M_t, two matrices of trips and commuting distances between TAZs were used to map out mean commuting distances (MCDs) by TAZ within about 30 km of Tiananmen Square (Figure 2).

In Figure 2, TAZs where MCD is less than or equal to the ARC distance of the metropolis (8.1 km) are shown in snowfield-ice polygons. Origin TAZs where MCD is greater than 8.1 km are shown in graduated black colors; the darker the colors, the longer the distances are. If it is assumed that TAZs where the distance is less than or equal to 8.1 km have achieved jobs–housing balance, then these balanced TAZs are evenly distributed across the space and so are the imbalanced TAZs.

TABLE 3 ARC, MRC, MaxRC, E, and C_u of Beijing and Other Cities

Study or Survey	Mode, Year	Sample Size (city, if not Beijing)	ARC (km)	ARC (min)	MRC (km)	MaxRC (km)	E	C_u
This study	Bus, 2008	216,844	8.1	36.0[a]	3.0	37.3	64	17
2005 survey[b]	Bus, 2005	6,651	8.4	40.5	—	—	—	—
2010 survey[b]	Bus, 2010	9,778	—	60.3	—	—	—	—
Liu and Wang (*53*)	Bus, 2007	307	—	46.3	—	—	—	—
Wang and Chai (*11*)	Bus, 2001	227	—	55.1	—	—	—	—
Zhao et al. (*14*)	Bus and rail rapid system, 2001	220	—	52.4	—	—	—	—
Liu et al. (*15*)	All, 2001	1,500 (Guangzhou)	4.5	—	1.9	—	58	—
	All, 2005	1,500 (Guangzhou)	5.0	—	2.7	—	44	—
Horner (*23*)	All, 1990	na (26 U.S. cities)	6.7~16.8	—	3.0~7.8	10.1~44.4	48~67	17~48
Horner and Mefford (*7*)	Non-Hispanic white, 1990, driving alone	na (Atlanta)	—	—	9.8	43.6	—	—
	Non-Hispanic white, 1990, bus	na (Atlanta)	—		5.9	27.5	—	—
	Non-Hispanic black, 1990, driving alone	na (Atlanta)	—	—	7.7	30.2	—	—
	Non-Hispanic black, 1990, bus	na (Atlanta)	—	—	6.0	18.8	—	—
	Non-Hispanic, other, 1990, driving alone	na (Atlanta)	—	—	6.2	35.1	—	—
	Non-Hispanic, other, 1990, bus	na (Atlanta)	—	—	5.8	24.7	—	—
	Hispanic white, 1990, driving alone	na (Atlanta)	—	—	7.2	35.3	—	—
	Hispanic white, 1990, bus	na (Atlanta)	—	—	6.2	21.7	—	—
Cropper and Gordon (*54*)	All, 1977	967[c] (Baltimore, Maryland)	15.4	—	6.5	—	58	—
Kim (*34*)	All, 1991	782[c] (Los Angeles, California)	24.6	—	16.5	—	33	—
Frost et al. (*22*)	All, 1991	na (London)	13.3[d]	—	10.8[d]	—	19	—
Buliung and Kanaroglou (*31*)	All, 1990	61,453[d] (Toronto, Canada)	11.4	—	4.0	—	65	—

NOTE: — = not available.
[a]Based on smart card data, in-bus time only.
[b]Citywide travel survey conducted by Beijing Municipal Government.
[c]Households, not workers.
[d]Including inward commuters from outside the limits of City of London.

These findings indicate that, unlike the conventional perception among local residents, the distance from an individual's residential location to the center (DtC) (Tiananmen Square) has little to do with his or her commuting distance or time. To validate this result, the relationship between MCDs by TAZ ($M = 8.1$ km, SD = 3.8 km) and DtC by TAZ ($M = 20.4$ km, SD = 15.8 km) was investigated with the Pearson correlation coefficient, which is often used to measure the strength of the linear relationship between two variables. Analyses were performed to ensure there were no violations of assumptions of normality and linearity. The results indicate that there was an only weak positive correlation between MCD and DtC ($r = 0.04$, $p = .25$, $n = 729$). Based on the above analysis, it was concluded that space (or more specifically DtC) does not play a significant role in determining bus commuters' jobs–housing balance or imbalance.

The areas (TAZs) with the most severe jobs–housing imbalance, however, tend to follow these spatial patterns:

1. Clustering in areas about 7 km northwest of Tiananmen Square,
2. Scattering near each other west and southwest of Tiananmen Square, and
3. Scattering around a half-circle with its center at Tiananmen Square and with a radius of 30 km (dashed lines in Figure 2 show the half-circle).

To investigate the physical environment and community characteristics of the above areas, experts ($n = 10$) with thorough local knowledge were consulted, field surveys were carried out, and Figure 2 was created. Based on the consultation and field surveys, five land use prototypes were identified in which bus commuters in Beijing could have severe jobs–housing imbalance. Table 4 summarizes the characteristics of these prototypes and provides a spatial index for the real-world examples in Figure 2. To locate concrete examples of these prototypes in Beijing, landmarks and directions are offered in Table 4.

To visualize the areas highlighted in Table 4, www.baidu.com, a leading search engine providing map services in China, was used to generate bird's-eye photos and detailed maps (see Figure 3).

Because specific bus commuters could not be identified directly from the smart card data, the study could not conduct surveys of or interviews with the commuters. Therefore, the causes of the severe

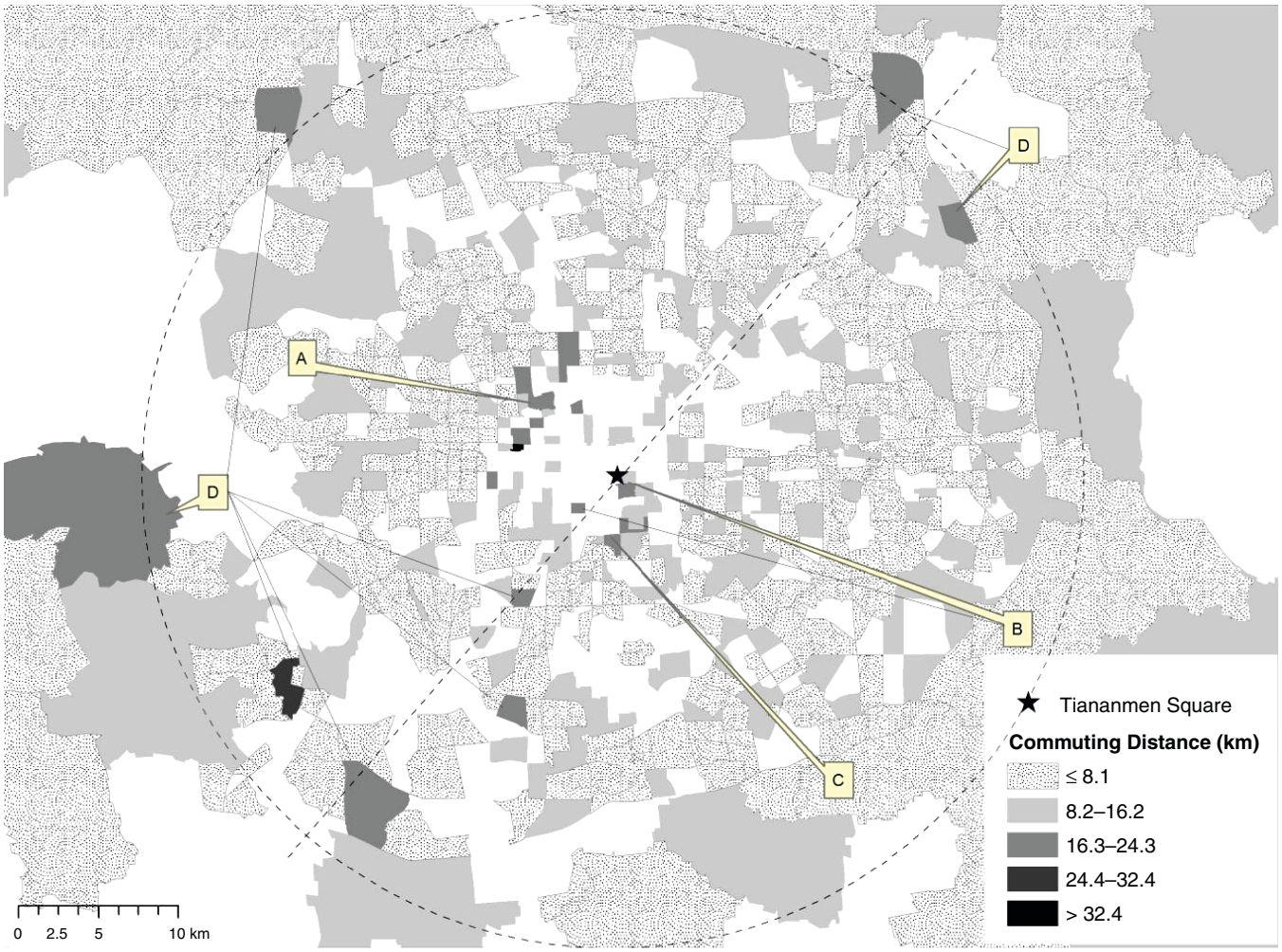

FIGURE 2 Mean commuting distances by TAZ in Beijing (TAZs without data not mapped).

TABLE 4 Land Use Prototypes of Extreme Jobs–Housing Imbalance of Bus Commuters

Prototype	Characteristics	Landmarks and Directions	Spatial Index in Figure 2
1	University campuses, hotels, and old Danwei compounds left with mostly apartment buildings	Minzu and Jiaotong Universities and areas in between; Beijing Technology and Business University and Capital Normal University (east campus) and areas adjacent to them; Beijing University of Aeronautics and Astronautics and Beijing University of Science and Technology and adjacent areas	A (areas around and areas to its northeast)
2	Parks with luxury hotels, high-end apartments, specialized research institutes, hospitals, and some mixed-use residential areas	Areas north of Yu Yuan Tan Park; area adjacent to Tian Tan Park in the east	A (south of A, the darkest area); the U-shaped area south of the star
3	Traditional Hu'tong with old, cheap, small, shared, and underserviced rental housing units	Areas between Qian Men Da Jie and Zhu Shi Kou Da Jie	B
4	Residential areas with mixed-age housing units adjacent to freeway interchanges or arterials, railways within the fifth ring road	Areas near Yong Ding Men and Nan Sha Wo Bridges	C
5	Low density, developing areas with relatively cheap housing units in the suburbs	Areas adjacent to the sixth ring road and Jingshi Freeway interchange; areas adjacent to Yan Chun Railway Station	D

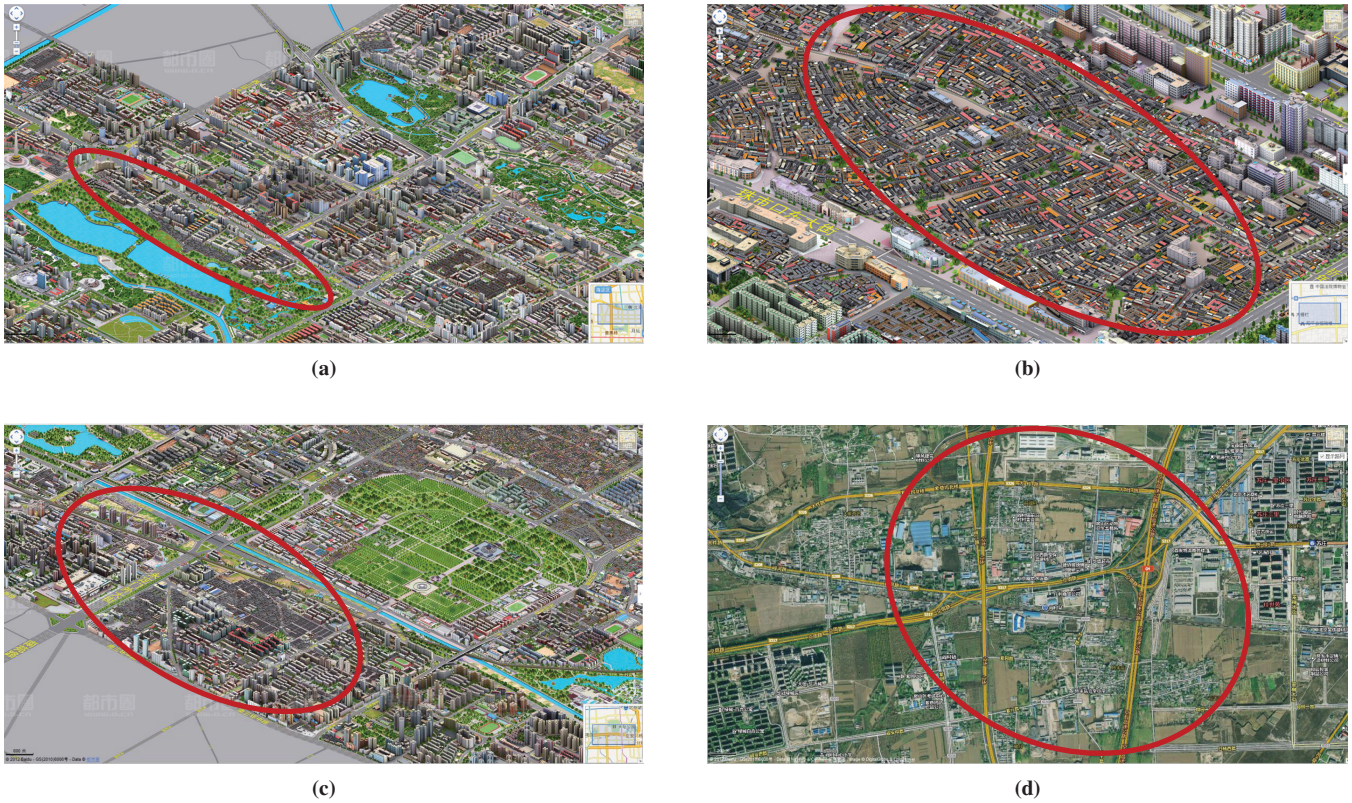

FIGURE 3 Visualization of prototypes: (*a*) Prototypes 1 and 2: within oval are areas north of Yu Yuan Tan Park, a hospital and Danwei Compounds, and two university campuses; (*b*) Prototype 3: within oval is traditional Hu'tong; (*c*) Prototype 4: within oval are new real estate developments coexisting with older, low-rise apartments; and (*d*) Prototype 5: within circle are low-density developing areas with cheap housing units in the suburb.

jobs–housing imbalance in Beijing could not be determined. Thus, the study obtained information from discussions with a small group of experienced local urban planners and analysts ($n = 10$) and several past studies (*11, 12, 47, 49–50*), which generated the speculated reasons and empirical evidence summarized in Table 5.

Based on the reasons listed in Table 5, it was possible to answer Question b posed above: what can be done about bus commuters' excess commuting or jobs–housing imbalance in Beijing?

First, it was important to understand why commuters chose to live in the prototype areas. In Prototype I, for instance, it was speculated that fresh graduates preferred to live on or around university campuses. The primary reasons for this choice were speculated to be efficiency in finding a roommate, affordability of housing and services, or familiarity with local communities (for those living at or around their alma mater).

Second, housing areas should have access to pleasant parks and other public infrastructure, such as quality schools and hospitals across the space, so that commuters do not need to sacrifice commuting distance for such access. In Prototype II, it was speculated that some commuters have sacrificed commuting distance. Empirical evidence in Zhao and He supported this speculation (*55*).

Third, there should be affordable housing options near employment centers so that employees do not have to live in areas that are cheap but far away from their workplace. This criterion is not easy to meet and most large-scale affordable housing projects (such as Hui Long Guan and Tian Tong Yuan with decades of history) in Beijing are located in the suburbs, where few established employment centers are located. An exception, according to Zhao and He (*55*), is Wang Jing and its hosting district, which provides employment opportunities for 75% of the local residents. (The hosting district is an important administrative unit in China. In Beijing's inner city, for instance, there are eight districts. Each district has its own government and is responsible for providing a wide range of services, like a large city in the United States.) All other large-scale affordable housing projects or new housing projects in Beijing's suburbs and their respective hosting districts provide employment opportunities only for 30% of the local residents. However hundreds and even thousands of small-scale affordable housing projects could be constructed by private parties. The private sector could be incentivized to build, own, or operate affordable apartments or units in job-rich and housing-deficient districts or areas.

Fourth, jobs could be moved closer to employees. There are many affordable housing projects in the suburbs of Beijing. Tax deductions and low-interest business loans could be selectively offered to encourage small employers to establish their business in the project areas. Similarly, self-employed residents in the suburbs could be incentivized and provided with on-the-job training. Another option would be to encourage telecommuting, which makes commuting and the jobs–housing balance much less relevant. Given the relatively low set-up costs, telecommuting may work best for Prototype V areas in Beijing. To make this innovation happen, however, would require working on both ends: the employee end and the employer end.

TABLE 5 Speculated Reasons for Severe Jobs–Housing Imbalance

Prototype	Speculations	Empirical Evidences[a]
1	Housing side: some fresh university graduates still live in cheap, shared apartments near their respective alma maters but work in another locale; other fresh graduates also prefer to live in or around a university campus, where they can efficiently find a roommate to reduce rent, cheap food, and services Job side: universities often do not offer a variety of jobs like central business districts and thus residents living in or around universities have to find a job in another locale	Many local housing online search engines offer tailored functions for users to efficiently locate housing near university campuses; a room's rent in a shared apartment near a university can be as cheap as a couple hundred RMB per month (see http://bj.ganji.com/fang1/daxue/bjgsdx/)
2	Housing side: some renters manage to live in affordable apartments or rooms in such a premium area Job side: specialized research institutes, luxury hotels, and hospitals offer only limited types of job opportunities such as researcher, nurse, doctor, and front desk clerk and thus local residents want other opportunities for work elsewhere; some workers simply made trade-offs between residential amenities and commuting distance	Funan residential area, an old community that is adjacent to Yu Yuan Tan Park, for instance, offers housing prices that are comparable to areas nearby despite its premium location, based on www.anjuke.com
3	Housing side: cheap rental housing units are relatively ample in Hu'tong Job side: few non-service–sector and well-paid job opportunities available in Hu'tong	Except hotels and restaurants, very few employers are located in Hu'tong, based on www.baidu.com
4	Housing side: housing units adjacent to freeway interchanges or arterials or railways are often relatively cheaper because of noise and pollution from through traffic, but this means affordability to some workers Job side: residential areas predominantly built for housing provide few job opportunities for local residents	Average second-hand apartment price to the southeast of Yong Dong Men Bridge, for instance, is around RMB 26,000/m^2 according to www.anjuke.com as of July 2012, which is cheaper than the average elsewhere around the inner city
5	Housing side: much cheaper housing prices than in the inner city Job side: low-density developing areas in the suburbs offer few job opportunities of any kind	New housing pricing near the sixth ring road and Jingshi Freeway, for instance, is around RMB 8,000–13,000/m^2, which is much cheaper than anywhere in the inner city

[a]Few public data were available; leading private online housing and generic search engines were used to obtain evidence.

Potential of Smart Card Data

Most studies of jobs–housing balance and related topics have relied on self-reported travel survey data. Because of the cost of administrating a large-scale travel survey and processing the relevant responses, the sample size of the survey is often quite small. In Table 3, for example, most of the other studies about Beijing have a sample with only a couple hundred observations. Although these samples may reasonably represent the commuter population's travel behaviors and sociodemographic characteristics, the samples often are not representative of global phenomena such as the jobs–housing balance.

In the case of Beijing, with workplace and housing information for a sample size of 6,000 from travel surveys, if the observations are evenly distributed across all the TAZs, there would be only four or five observations for each TAZ, because there are 1,118 TAZs. It would be technically challenging to deduce any useful insights about the metropolitan-scale jobs–housing balance based on four or five observations for each TAZ. In comparison, smart card data can efficiently and economically provide workplace and housing information for samples that are 40 or even 50 times larger. These data would facilitate studies of metropolitan-scale jobs–housing balance and significantly increase the representation and reliability of related analyses. Therefore, smart card data have provided an alternative way for analysts to study jobs–housing balance and related topics at the metropolitan scale.

There are enhancements that can be made to increase the value of smart card data, which contain no socioeconomic information about cardholders or commuters. One proposed enhancement would be to link smart card data to resident card data for all cardholders who authorize the data administrator to do so. In China and many other countries, resident card data are universally available and at least provide information such as age, gender, marriage status, and current home address of the resident. The other proposed enhancement would be to ask anyone who purchases a smart card to voluntarily fill in an anonymous form that collects a minimum amount of socioeconomic information about him or her, which would be of interest to policy analysts. In return, the respondent could be given some bonus monetary value on the smart card or could be allowed to obtain a new smart card for free if the original card is lost, a benefit that is not offered currently.

CONCLUSIONS

In this study, massive smart card data were used to obtain 216,844 bus commuters' workplace and residential locations. These data enabled a jobs–housing study of bus commuters in a metropolis with a much larger sample size than most other studies. This study found that bus commuters in Beijing (*a*) have a shorter ARC and MRC than commuters in four auto-dependent Western cities with comparable population and land use sizes and (*b*) have a longer ARC and MRC than commuters of all modes in Guangzhou, a metropolis that is half the size of Beijing. Overall, Beijing's bus commuters face severe excess commuting ($E = 64\%$) but still only use a relatively small portion of the commute potential ($C_u = 17\%$). As the city expands and if nothing is done about correcting the jobs–housing imbalance, Beijing's bus commuters could encounter even more severe excess commuting. Bus commuting time differences between two local travel surveys in 2005 and in 2010 have partially reflected this trend.

To help reverse the trend, this study has supplemented the smart card data with local expert knowledge, field surveys, and information provided by online housing search engines to investigate bus commuters' jobs–housing imbalance in Beijing and ways to correct it. The study established five land use prototypes of jobs–housing imbalance. It

used local experts to speculate on reasons for the imbalance of each prototype. It also proposed solutions to the imbalance based on the prototypes and speculated reasons. Overall, the study has expanded the relatively static analysis of the status quo (i.e., one-time quantification of a city's jobs–housing balance, commuting efficiency, and excess commuting) of a city into one of relevant dynamics. Understanding the dynamics enables analysts to propose more relevant solutions to the problems identified. For other researchers who want to use smart card data, this study may provide a good example and a generic roadmap regarding how to enhance the value of smart card data with complementary data and knowledge.

With all of the above merits, this study can still be improved in at least three aspects in the future. First, the study should be linked to local household travel surveys, particularly the responses given by bus commuters. This link would provide more information on commuters' job, housing, and transportation decisions and concerns. The additional information would serve to validate or invalidate existing expert speculations about commuters. Of course, there are barriers to be overcome, as there has been a tradition among local agencies to hoard survey responses and share them within the agencies.

Second, data should be collected to study the jobs–housing balance and related issues among auto and bicycling commuters too. Since this study did not make any comparisons between the auto and bicycle commuters and bus commuters, it was not determined whether the problems identified in this study are unique to bus commuters.

Third, the study would be greatly enhanced by smart card data that include rail rapid system swipe information. The smart card data administrator has such information but was unwilling to provide it for this study. Of course, adding this extra information would make smart card data processing and validation more complicated and challenging. However, the additional information would enable a better understanding of the jobs–housing balance of more commuters, in particular, those commuters who primarily or solely use the rail rapid system or those who commute by bus and rail rapid system. Such an expanded analysis would be extremely important for a metropolis like Beijing, which is experiencing a growing rail rapid system and an increased share of rail rapid system commuters.

REFERENCES

1. California Department of Housing and Community Development. Job Housing Balance Program Final Report to the Legislature. 2007.
2. California Planning Roundtable. Deconstructing Jobs Housing Balance. 2008.
3. Cervero, R. Jobs–Housing Balancing and Regional Mobility. *Journal of the American Planning Association,* Vol. 55, No. 2, 1989, pp. 136–150.
4. Cervero, R. Jobs–Housing Balance as Public Policy. *Urban Land,* Vol. 50, No. 2, 1991, pp. 10–14.
5. Downs, A. *Stuck in Traffic: Coping with Peak-Hour Traffic Congestion.* Brookings Institution, Washington, D.C., 1992.
6. Boarnet, M.G., H.-P. Hsu, and S.L. Handy. Draft Policy Brief: Impact of Jobs–Housing Balance on Passenger Vehicle Use and Greenhouse Gas Emissions Based on a Review of the Empirical Literature. California Air Resources Board, Sacramento, 2011.
7. Horner, M.W., and J.N. Mefford. Investigating Urban Spatial Mismatch Using Job–Housing Indicators to Model Home–Work Separation. *Environment and Planning A,* Vol. 39, No. 6, 2007, pp. 1420–1440.
8. Preston, V., and S. McLafferty. Spatial Mismatch Research in the 1990s: Progress and Potential. *Papers in Regional Science,* Vol. 78, No. 4, 1999, pp. 387–402.
9. Taylor, B.D., and P.M. Ong. Spatial Mismatch or Auto Mismatch—An Examination of Race, Residence, and Commuting in U.S. Metropolitan Areas. *Urban Studies,* Vol. 32, No. 9, 1995, pp. 1453–1473.
10. Bauder, H. Reflections on the Spatial Mismatch Debate. *Journal of Planning Education and Research,* Vol. 19, No. 3, 2000, pp. 316–320.
11. Wang, D., and Y. Chai. The Jobs–Housing Relationship and Commuting in Beijing, China: The Legacy of Danwei. *Journal of Transport Geography,* Vol. 17, No. 1, 2009, pp. 30–38.
12. Wang, D.G., and Y.W. Chai. Structural Equation Analysis of Interactions Between Job-Housing. Relations, Transport Mode, and Commuting Times in Beijing. In *Transportation and the Economy* (W.H.K. Lam and J. Yan, eds.), 2005, pp. 359–368.
13. Wang, E.R., J.P. Song, and T. Xu. From "Spatial Bond" to "Spatial Mismatch": An Assessment of Changing Jobs–Housing Relationship in Beijing. *Habitat International,* Vol. 35, No. 2, 2011, pp. 398–409.
14. Zhao, P.J., B. Lu, and G. de Roo. Impact of the Jobs–Housing Balance on Urban Commuting in Beijing in the Transformation Era. *Journal of Transport Geography,* Vol. 19, No. 1, 2011, pp. 59–69.
15. Liu, W., X. Yan, Y. Fang, and X. Cao. Related Characteristics and Mechanisms for Excess Commuting in Guangzhou. *Acta Geographica Sinica,* Vol. 63, No. 10, 2008, pp. 1085–1096.
16. Horner, M.W. Spatial Dimensions of Urban Commuting: A Review of Major Issues and Their Implications for Future Geographic Research. *The Professional Geographer,* Vol. 56, No. 2, 2004, pp. 160–173.
17. Ma, K.R., and D. Banister. Excess Commuting: A Critical Review. *Transport Reviews,* Vol. 26, No. 6, 2006, pp. 749–767.
18. O'Kelly, M.E., and W. Lee. Disaggregate Journey-to-Work Data: Implications for Excess Commuting and Jobs–Housing Balance. *Environment and Planning A,* Vol. 37, No. 12,2005, pp. 2233–2252.
19. Hamilton, B.W., and A. Röell. Wasteful Commuting. *Journal of Political Economy,* Vol. 90, No. 5, 1982, 1035–1053.
20. White, M.J. Urban Commuting Journeys Are Not "Wasteful." *Journal of Political Economy,* Vol. 96, No. 5, 1988, pp. 1097–1110.
21. Cervero, R. Jobs–Housing Balance Revisited—Trends and Impacts in the San Francisco Bay Area. *Journal of the American Planning Association,* Vol. 62, No. 4, 1996, pp. 492–511.
22. Frost, M., B. Linneker, and N. Spence. Excess or Wasteful Commuting in a Selection of British Cities. *Transportation Research Part A: Policy and Practice,* Vol. 32, No. 7, 1998, pp. 529–538.
23. Horner, M.W. Extensions to the Concept of Excess Commuting. *Environment and Planning A,* Vol. 34, No. 3, 2002, pp. 543–566.
24. Crane, R. The Influence of Uncertain Job Location on Urban Form and the Journey to Work. *Journal of Urban Economics,* Vol. 39, No. 3, 1996, pp. 342–356.
25. Gordon, P., H.W. Richardson, and M.-J. Jun. The Commuting Paradox Evidence from the Top Twenty. *Journal of the American Planning Association,* Vol. 57, No. 4, 1991. pp. 416–420.
26. Kim, C. Commuting Time Stability: A Test of a Co-Location Hypothesis. *Transportation Research Part A: Policy and Practice,* Vol. 42, No. 3, 2008, pp. 524–544.
27. Kwan, M.P. Gender and Individual Access to Urban Opportunities: A Study Using Space-Time Measures. *Professional Geographer,* Vol. 51, No. 2, 1999, pp. 210–227.
28. Giuliano, G., and K. Small. Is the Journey to Work Explained by Urban Structure? *Urban Studies,* Vol. 30, No. 9, 1993, pp. 1485–1500.
29. Giuliano, G. Is Jobs–Housing Balance a Transportation Issue? In *Transportation Research Record 1305,* TRB, National Research Council, Washington, D.C., 1991, pp. 305–312.
30. Peng, Z.R. The Jobs–Housing Balance and Urban Commuting. *Urban Studies,* Vol. 34, No. 8, 1997, pp. 1215–1235.
31. Buliung, R.N., and P.S. Kanaroglou. Commute Minimization in the Greater Toronto Area: Applying a Modified Excess Commute. *Journal of Transport Geography,* Vol. 10, 2002, pp. 177–186.
32. Rodríguez, D.A. Spatial Choices and Excess Commuting: A Case Study of Bank Tellers in Bogotá, Colombia. *Journal of Transport Geography,* Vol. 12, No. 1, 2004, pp. 49–61.
33. Horner, M.W., and A.T. Murray. Excess Commuting and the Modifiable Areal Unit Problem. *Urban Studies,* Vol. 39, No. 1, 2002, pp. 131–139.
34. Kim, S. Excess Commuting for Two-Worker Households in the Los Angeles Metropolitan Area. *Journal of Urban Economics,* Vol. 38, No. 2, 1995, pp. 166–182.
35. Layman, C.C., and M.W. Horner. Comparing Methods for Measuring Excess Commuting and Jobs–Housing Balance: Empirical Analysis of Land Use Changes. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2174.* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 110–117.

36. Ma, K. R., and D. Banister. Extended Excess Commuting: A Measure of the Jobs–Housing Imbalance in Seoul. *Urban Studies,* Vol. 43, No. 11, 2006, pp. 2099–2113.
37. Merriman, D., T. Ohkawara, and T. Suzuki. Excess Commuting in the Tokyo Metropolitan Area: Measurement and Policy Simulations. *Urban Studies,* Vol. 32, No. 1, 1995, pp. 69–85.
38. Murphy, E. Excess Commuting and Modal Choice. *Transportation Research Part A: Policy and Practice,* Vol. 43, No. 8, 2009, pp. 735–743.
39. Scott, D. M., P. S. Kanaroglou, and W. P. Anderson. Impacts of Commuting Efficiency on Congestion and Emissions: Case of the Hamilton CMA, Canada. *Transportation Research Part D: Transport and Environment,* Vol. 2, No. 4, 1997, pp. 245–257.
40. Suzuki, T., and S. Lee. Jobs–Housing Imbalance, Spatial Correlation, and Excess Commuting. *Transportation Research Part A: Policy and Practice,* Vol. 46, No. 2, 2012, pp. 322–336.
41. Yang, J. Policy Implications of Excess Commuting: Examining the Impacts of Changes in U.S. Metropolitan Spatial Structure. *Urban Studies,* Vol. 45, No. 2, 2008, pp. 391–405.
42. Levinson, D. M. Accessibility and the Journey to Work. *Journal of Transport Geography,* Vol. 6, 1998, pp. 11–21.
43. Cervero, R. *America's Suburban Centers: A Study of the Land Use-Transportation Link.* Unwin Hyman, Boston, Mass. 1989.
44. Cervero, R., and M. Duncan. Which Reduces Vehicle Travel More: Jobs–Housing Balance or Retail–Housing Mixing? *Journal of the American Planning Association,* Vol. 72, No. 4, 2006, pp. 475–490.
45. Kockelman, K. M. Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from San Francisco Bay Area. In *Transportation Research Record 1607,* TRB, National Research Council, Washington, D.C., 1997, pp. 116–125.
46. Miller, E. J., and A. Ibrahim. Urban Form and Vehicular Travel: Some Empirical Findings. In *Transportation Research Record 1617,* TRB, National Research Council, Washington, D.C., 1998, pp. 18–27.
47. Li, Q., and X. Li. The Characteristics of Residents' Working-Trips in Inner-Suburbs of Beijing (in Chinese). *Urban Problems,* Vol. 7, 2007, pp. 55–59.
48. Liu, Z., Y. Zhang, and Y. W. Chai. Home–Work Separation in the Context of Institutional and Spatial Transformation in Urban China: Evidence from the Beijing Household Survey Data (in Chinese). *Urban Studies,* Vol. 9, 2009, pp. 110–117.
49. Meng, B. The Spatial Organization of the Separation Between Jobs and Residential Locations in Beijing (in Chinese). *Acta Geographica Sinica,* Vol. 64, No. 12, 2009.
50. Meng, B., L. Zheng, and H. Yu. Commuting Time Change and Its Influencing Factors in Beijing (in Chinese). *Progress in Geography,* Vol. 30, No. 10, 2011, pp. 1218–1224.
51. Zhou, S., and Y. Liu. The Situation and Transition of Jobs–Housing Relocation in Guangzhou, China (in Chinese). *Acta Geographica Sinica,* Vol. 65, No. 2, 2010.
52. Long Y., and J.-C. Thill. 2012. Combining Smart Card Data, Household Travel Surveys and Land Use Patterns for Identifying Housing-Jobs Relationships in Beijing. Working Paper, Beijing Institute of City Planning.
53. Liu, Z., and M. Wang. Job Accessibility and Its Impacts on Commuting Time of Urban Residents in Beijing: From a Spatial Mismatch Perspective (in Chinese). *Acta Geographica Sinica,* Vol. 66, No. 4, 2011, pp. 457–467.
54. Cropper, M. L., and P. Gordon. Investigating Urban Spatial Mismatch Using Job–Housing Indicators to Model Home–Work Separation. *Journal of Urban Economics,* Vol. 29, 1991. pp. 2–13.
55. Zhao, X., and Y. He. Spatial Mismatch Between Housing and Employment of Beijing (in Chinese). *Urban Problems,* Vol. 5, 2010, pp. 56–60.

The Bus Transit Systems Committee peer-reviewed this paper.