Spatial Dimensions of Job Accessibility by Commuting Time and Mode in the Tokyo Metropolitan Area

Mizuki KAWABATA and Akiko TAKAHASHI

Abstract: Accessibility addresses a wide range of urban and transportation issues and is a subject of increasing interest. In this article we utilize GIS to measure and examine intra-metropolitan variation in job accessibility by commuting time and mode for Tokyo. In order to take into account spatial distributions of jobs and workers as well as travel modes, we employ the floating catchment area method and estimate origin-to-destination commuting times for auto and public transit. Three-dimensional visualization reveals that job accessibility varies considerably by location and commuting mode, but the spatial variability tends to lessen as the threshold of travel time lengthens. The empirical measures of job accessibility provide data useful for examining jobs-housing balance and commuting patterns.

Keywords: Job accessibility, commuting time, commuting mode, three-dimensional visualization, Tokyo metropolitan area

1. Introduction

Accessibility, defined as the number of opportunities available within a given distance or travel time (Hanson, 1995), is a subject of increasing interest among researchers and policy makers. One reason is that accessibility can address a wide range of urban and transportation issues (see, for example, Cervero et al., 1999; Geurs and Wee, 2004; Kawabata, 2003; Kawabata and Shen, forthcoming). Another reason is the advancement of desktop GIS and spatial data that has greatly simplified accessibility analysis and enabled more effective spatial presentation (Tanaka, 2004).

Among current urgent urban and transportation issues are reducing commuting duration and automobile usage. These issues are particularly brought to light by the recently enacted Kyoto Protocol, which calls for a reduction in gasoline consumption in order to prevent global warming. The relationship between jobs-housing balance and commuting behavior has been actively examined and debated in order to better target those objectives.

One body of literature uses optimization techniques to measure wasteful commuting or excess commuting that represents the difference between actual and minimal commuting given real distributions of jobs and housing (Hamilton, 1982; Merriman et al., 1995; Rodríguez, 2004; Suzuki, 1992; White 1988). Another body of literature investigates the relationship between jobs-housing balance and commuting behavior (Cervero, 1996; Giuliano, 1991; Giuliano and Small, 1993; Peng, 1997; Wachs et al., 1993). These studies have generated much discussion about whether seeking to balance job and housing locations is a viable and effective strategy in changing commuting behavior.

When taking into account spatial distributions of jobs and workers, job accessibility, a type of accessibility, can indicate geographical balance between jobs and workers. Yet the extent to which job accessibility varies by location and commuting mode has not been thoroughly examined in Tokyo. In this article, therefore, we utilize GIS to measure and examine intra-metropolitan variations in job accessibility by commuting time and mode for the Tokyo metropolitan area. In order to take into account spatial distributions of jobs and workers as well as travel modes, we employ the floating catchment area...
(FCA) approach and estimate origin-to-destination (OD) commuting times for auto and public transit. The computed accessibility measures are visualized in three dimensions (3D) to better understand spatial variations in job accessibility.

This paper starts with a description of the study area in Section 2. Next, we explain the methodological framework to calculate job accessibility in Section 3 and present results in Section 4. In Section 5 we summarize findings and discuss directions of future research.

2. Study Area

The study area is the Tokyo metropolitan area covering Tokyo, as well as Kanagawa, Saitama, Chiba, and the southern portion of Ibaraki prefectures (Figure 1-(a)). In this study, the central business district (CBD) includes Chiyoda-ku, Chuo-ku, and Minato-ku. Table 1 presents basic characteristics for the entire metropolitan area as well as for the central city defined as the Tokyo Wards Region (the 23 wards of Tokyo).

<table>
<thead>
<tr>
<th>Characteristics of the Tokyo metropolitan area</th>
<th>Entire metro area</th>
<th>Central city</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area (sq. km)</td>
<td>15,000</td>
<td>620</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>34.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Mean travel time to work by origin zones (min.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All modes</td>
<td>43</td>
<td>38</td>
</tr>
<tr>
<td>Auto</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>Public transportation</td>
<td>63</td>
<td>49</td>
</tr>
<tr>
<td>Means of commuting to work (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>Public transportation</td>
<td>48</td>
<td>70</td>
</tr>
<tr>
<td>Walking</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Other means</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of the Tokyo metropolitan area

The Tokyo metropolitan area is the largest metropolitan area in the world. It comprises approximately 15,000 square kilometers and accommodates nearly 35 million people. The central city covers 620 square kilometers of land and is home to over 8 million residents.

The metropolitan-wide average commuting time is 43 minutes, but commuting time differs greatly by travel mode and location. The average commuting time for public transit is 63 minutes, which is about twice the average time for auto users’ 32 minutes. The average commuting time for auto users is shorter for the entire metropolitan area (32 minutes) than for the central city (37 minutes). The average commuting time for public transit riders, on the other hand, is much longer for the entire metropolitan area (63 minutes) than for the central city (49 minutes).

Tokyo commuters are more likely to use public transportation than autos, especially within the central city. About half of metropolitan workers use public transportation to commute to work, while approximately one-third of workers use autos. The proportion of public transit ridership for central-city residents is notably high at 70%, whereas the proportion of auto drivers is just 10%. We point out, however, that recent data indicate that auto usage has been increasing. Between 1988 and 1998, the proportion of metropolitan residents who use autos increased from 27% to 33%. The increases in auto usage in the outer suburbs are especially notable. In the southern region of Ibaraki Prefecture, for instance, auto usage rose, from 52% to 65% (Tokyo Metropolitan Region Transport Planning Commission, 1999).

3. Measuring Job Accessibility

3.1 Measurement of job accessibility

Job accessibility is measured in various ways depending on the purpose of its use (reviews are given in, for example, Handy and Niemeier, 1997; Harris, 2001; Tanaka, 2004). In this study, we calculate job accessibility that takes into account spatial distributions of both supply (jobs) and demand (workers) sides of the labor market as well as travel modes. These factors have rarely been incorporated together in previous calculations. In many cases job accessibility is calculated factoring in the supply side only or is computed for mixed travel modes or only for auto travels. Ignoring either of these factors is likely to yield inaccurate or even misleading results (Harris, 2001; Shen, 1998), because jobs and workers are not uniformly distributed across a metropolitan area and because commuting time differs among travel modes.
In this study, therefore, we calculate demand-adjusted, travel-mode differentiated job accessibility by employing the floating catchment area (FCA) approach and estimating origin to destination (OD) commuting times for auto and public transit. Each FCA is defined by the total zone area accessible within a given travel time by a particular mode. We calculate three types of job accessibility: 1) job accessibility for auto commuters, 2) job accessibility for public transit commuters, and 3) general job accessibility combining job accessibility for auto and public transit. The following formulae, based on Shen’s (1998) accessibility framework, are used for calculating the three measures of accessibility:

\[ A_{i}^{\text{auto}} = \sum_{j} \frac{E_{ij}}{\sum_{k} \alpha_{k}W_{k} + \sum_{k} (1 - \alpha_{k})W_{k}} \]  

(1)

\[ A_{i}^{\text{tran}} = \sum_{j} \frac{E_{ij}}{\sum_{k} \alpha_{k}W_{k} + \sum_{k} (1 - \alpha_{k})W_{k}} \]  

(2)

\[ A_{i}^{G} = \alpha_{i}A_{i}^{\text{auto}} + (1 - \alpha_{i})A_{i}^{\text{tran}} \]  

(3)

\( A_{i}^{\text{auto}} \) and \( A_{i}^{\text{tran}} \) are measures of job accessibility in resident zone \( i \) for auto commuters and public transit commuters, respectively. \( A_{i}^{G} \) is a general measure of job accessibility in zone \( i \) combining \( A_{i}^{\text{auto}} \) and \( A_{i}^{\text{tran}} \). Travel times between zone \( i \) and zone \( j \) for auto and public transit are \( t_{ij}^{\text{auto}} \) and \( t_{ij}^{\text{tran}} \), respectively. The travel time threshold is expressed as \( t_{0} \). The number of jobs in zone \( j \) is rendered as \( E_{j} \), and the number of workers living in zone \( k \) is indicated by \( W_{k} \). We use \( \alpha_{k} \) as the proportion of commuters who use autos in zone \( k \). In computing these accessibility measures, we assume that non-auto commuters use public transit. Note that the center of FCA for jobs is at a resident zone for which accessibility value is calculated, but the center of FCA for workers is at a workplace zone so that workers who can reach those jobs within a given travel time threshold are incorporated. A similar approach is employed by Luo and Wang (2003) that describes the concept behind the approach in detail.

Note also that job accessibility computed from the aforementioned equations better represents job accessibility than using the simple ratio of jobs to resident workers per area, as the simple ratio takes into account neither jobs available outside a worker’s resident area nor workers commuting into that area from outside. The simple ratio is, therefore, likely to overestimate job accessibility around CBD and to underestimate suburban job accessibility.

The geographic unit of analysis is the plan base zone (keikaku-kihon zone) as defined for the 1998 Person Trip (PT) Survey. The Tokyo metropolitan area has 595 plan base zones for the 1998 survey (Figure 1-(a)). Data on the numbers of jobs and workers are extracted from the city-level data of the 2000 Population Census of Japan. Workers are defined as persons in the labor force including both the employed and unemployed. We converted city-level census data to plan base zone-level data, using area-weighted factors created with the overlay function of GIS.

The job access calculations in equations 1 and 2 use commuting times by travel mode for a complete set of OD zones. The PT Survey provides data on OD commuting times by commuting mode. However, because PT data are sample-based, a number of OD pairs do not have samples; out of 354,025 OD pairs (595×595 zones), 286,521 auto user pairs and 252,520 public transit user pairs have no reported commuting times. We therefore construct complete OD matrices as described in the following subsection.

3.2 Estimating OD commuting times

We use GIS and the following two data sets to estimate commuting times by car and public transit for complete OD pairs: spatial data on roads, railroads, and stations, which are extracted from 2001 GISMAP 25000V (Hokkaido-Chizu Co, Ltd.); and OD average morning peak (7:00 - 9:30 am) commuting times including waiting times by car and public transit, which are compiled from the 1998 PT Survey.

We estimate OD commuting times for trips between plan base zone centroids. Travel times for all inter-zone OD pairs (353,430 = 595×594 pairs) are modeled using GIS. For auto commuters, we first
calculate the length of each road link, assigning average speed during weekday peak time by road type to each link using data from 1999 Road Transportation Census for the Kanto-Rinkai block. We then calculate travel time for each link by dividing length by speed and identify minimum travel time path for each inter-zone OD pair. Finally, we compute a total travel time for each path.

For public transit users, we estimate a total time that combines the following three travel times for each OD pair: travel time from the origin zone’s centroid to its nearest station on the road network \((TIME_{(1)})\); travel time from the station nearest the origin zone’s centroid to a station closest to the centroid of a destination zone on transit network \((TIME_{(2)})\); and travel time from the station closest to the destination zone’s centroid on road network \((TIME_{(3)})\). The following three assumptions are made for the estimation: 1) first preference for means of commuting is railway; 2) local trains that stop at every station are used; and 3) there is no waiting or transfer time.

\(TIME_{(1)}\) and \(TIME_{(3)}\) are calculated as travel times on the shortest-distance paths on roads, assuming that people walk if walking time is equal to or less than 15 minutes. Otherwise, people take buses. Walking speed is set at 80 meters per minute, the official speed estimation of the Real Estate Fair Council in Japan. People therefore are assumed to walk if the distance is 1,200 meters or less (=80 meters per minute \(\times\) 15 minute). If the distance exceeds 1,200 meters, people take buses. Bus speed is set at 20 kilometers an hour, about the average speed of long and short-distance buses, which is calculated with data in the Tokyo Bus Association (2003).

\(TIME_{(2)}\) is computed as follows. First, average train speed by train type is assigned to each railroad link. The speed is calculated for Tokyo-bound trains arriving at terminal stations between 8:30am and 9:00am using data in the Myline Tokyo Timetable (Mae, 2004). Second, the minimum travel-time path is identified and travel time for each path is calculated. \(TIME_{(1)}, TIME_{(2)},\) and \(TIME_{(3)}\) are then totaled to obtain total commuting time for each OD pair.

Next, we employ Wang’s (2003) approach to adjust the GIS-modeled inter-zone commuting times by estimating the following regression models:

\[
TIME^{\text{PAUTO}}_{ij} = \beta_0 + \beta_1 TIME^{\text{GISAUTO}}_{ij} + \beta_2 WDENS_i + \beta_3 JDENS_j + \epsilon, \quad (4)
\]

\[
TIME^{\text{PTPUB}}_{ij} = \beta_0 + \beta_1 TIME^{\text{GISPUB}}_{ij} + \beta_2 WDENS_i + \beta_3 JDENS_j + \epsilon. \quad (5)
\]

\(TIME^{\text{PAUTO}}_{ij}\) and \(TIME^{\text{PTPUB}}_{ij}\) are the PT Survey’s average commuting times from zone \(i\) to zone \(j\) for auto and public transit users, respectively. \(TIME^{\text{GISAUTO}}_{ij}\) and \(TIME^{\text{GISPUB}}_{ij}\) are the GIS-modeled travel times from zone \(i\) to zone \(j\) for auto and public transit, respectively. The density of workers (the number of workers per square kilometers) in origin zone \(i\) is given by \(WDENS_i\), and the density of jobs (the number of jobs per square kilometers) in destination zone \(j\) is represented by \(JDENS_j\). The error term is indicated by \(\epsilon\).

Job and worker figures are from the 2000 Population Census of Japan. The density variables are included to capture congestion in residence and workplace zones. We would expect that increases in the densities imply increasing congestion, which in turn lengthens commuting times. Congestion in the other zones along the commuting paths is not included for the sake of simplicity.

The regression results are presented in Table 2. All estimated coefficients are significant at the one percent level. The GIS-modeled OD travel times have strong and significant effects on the PT Survey’s average OD times. Both the density variables have positive effects, but the magnitude of the effect for public transit is much less than that for autos. This result is reasonable given that congestion is less likely to affect train times than to impact auto times. The \(R^2\) values of 0.45 and 0.49 suggest fairly good fits.
Table 2. Regression results of OD commuting times

<table>
<thead>
<tr>
<th>Variable</th>
<th>Auto Coef.</th>
<th>t</th>
<th>Public transit Coef.</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME_AUTO_0</td>
<td>0.877</td>
<td>233.10</td>
<td>0.686</td>
<td>300.50</td>
</tr>
<tr>
<td>WDENS_i</td>
<td>0.001</td>
<td>31.91</td>
<td>0.00003</td>
<td>10.68</td>
</tr>
<tr>
<td>JDENS_j</td>
<td>0.0002</td>
<td>21.35</td>
<td>0.00003</td>
<td>6.42</td>
</tr>
<tr>
<td>Number of observations</td>
<td>66,911</td>
<td>100,968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.45</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Observations with no data are excluded from the estimations.

The regression results are then used to estimate OD commuting times for all inter-zone travels. Ten minutes is assigned to all intra-zone travels. We selected 10 minutes arbitrarily, but it is below the travel-time thresholds used in this study. As intra-zone times are below the travel-time thresholds, jobs and workers in a resident zone are incorporated in the accessibility calculations. Finally, we combine the estimated inter-zone and intra-zone data to create complete OD commuting times for auto and public transit. A more detailed explanation of the OD commuting time estimations are documented in Kawabata and Takahashi (2004).

It is important to note that the estimation method proposed above has some limitations. The GIS modeling does not take into account waiting and transfer times. In the case of public transit, rapid and express trains are not considered. Gaps between estimated and actual travel times between centroids and nearest stations may be significant. A significant gap is likely to occur in large peripheral zones where transit coverage is scarce. Despite these limitations, the OD commuting time estimates are sufficient for the purpose of this study’s macro-scale analysis. Methods to provide better estimates will be examined in future work.

4. Results

First, we present maps of the spatial distributions of jobs and workers as well as the distributions of commuting modes and time incorporated into job accessibility calculations (Figure 1). The density and ratio maps (Figures 1-(b)–(d)) are visualized in 3D, which helps us understand considerable spatial variations. We use the same extrusion factor for the density maps for the purpose of comparison. Both jobs and workers are centralized around the urban center, but jobs are far more centralized than workers. Job concentrations around CBD are markedly high, as reflected in the extremely high ratios of jobs to workers around CBD.

We use two-dimensional (2D) maps for commuting modes and time (Figures 1-(e)–(h)) because distributional patterns become less clear with 3D maps, especially for the doughnut-type distribution of the average commuting time by public transit (Figure 1-(h)). Considerable spatial variations in commuting patterns are visually apparent. Autos are less likely to be used as a means of commuting in central zones but are more likely to be used in suburban zones, especially in the outer suburbs. Conversely, public transportation is used heavily in central zones but is much less likely to be used in the outer suburbs. Spatial variation in commuting time for autos appears to be more limited than that for public transit. The average commuting time by auto is somewhat longer in central zones than in suburban zones. The pattern is reversed for public transit. The average transit commuting time is considerably longer in suburban zones, particularly in the outer suburbs, than in central zones.

Figure 2 visualizes computed measures of job accessibility for the thresholds of 30, 45, 60, and 90 minutes. To make the maps comparable, we use the same degree of extrusion for all maps. The mean and standard deviations of job-access values by commuting mode and time are reported in Table 3. Note that means are unweighted zonal averages. The weighted average equals the ratio of total number of jobs to total number of workers in the whole study area (0.94 = 16,662,000 jobs / 17,818,000 workers). An accessibility value higher than this ratio, therefore, is considered relatively high job accessibility, and a value below the ratio is considered relatively low job accessibility.
Figure 1. Characteristics of Tokyo metropolitan area
Figure 2. Job accessibility by commuting time and mode
Table 3. Mean and standard deviation of job accessibility by threshold time and travel mode

<table>
<thead>
<tr>
<th>Time</th>
<th>Auto</th>
<th>Transit</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 min.</td>
<td>2.37</td>
<td>1.08</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>(5.18)</td>
<td>(3.24)</td>
<td>(3.31)</td>
</tr>
<tr>
<td>45 min.</td>
<td>3.72</td>
<td>0.67</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>(5.34)</td>
<td>(1.92)</td>
<td>(2.03)</td>
</tr>
<tr>
<td>60 min.</td>
<td>1.83</td>
<td>0.71</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
<td>(0.80)</td>
<td>(0.64)</td>
<td>(0.55)</td>
</tr>
<tr>
<td>90 min.</td>
<td>1.10</td>
<td>0.84</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(0.38)</td>
<td>(0.24)</td>
</tr>
</tbody>
</table>

Note: Standard deviations are in parentheses.

Several observations can be made from the 3D maps and table. First, job accessibility varies considerably across space. Overall, job accessibility is much higher in central zones, particularly those around CBD, than in suburban zones, but some suburban zones offer high accessibility.

Second, the spatial variability of job accessibility tends to lessen with a longer threshold time, as indicated by the 3D maps as well as standard deviations reported in Table 3. This tendency can be linked to the different size of FCA that is defined by the threshold time. With the 30-minute threshold, for example, the extent to which people travel is rather limited (i.e., relatively small FCA), and a job-access measure naturally becomes similar to a simple jobs-to-worker ratio per zone (see Figure 1-(d)). With a longer threshold time, on the other hand, people travel farther (i.e., larger FCA), and the accessibility distribution becomes more even. Given that a longer threshold time enables more suburban workers to reach jobs concentrated in and around CBD, less variability with a longer threshold time is a reasonable outcome. The 3D maps made these results visually apparent.

Third, job accessibility is higher for auto users than for public transit users. The gap between auto and transit accessibility, however, tends to narrow as the threshold time lengthens.

The maps suggest some relationships between job accessibility and commuting patterns. Relationships of particular interest are whether higher job accessibility for public transit reduces auto usage and whether higher job accessibility by a particular mode shortens commuting time for that mode. The maps indicate that areas with higher transit job accessibility tend to be areas with lower rates of car use (see Figure 2-(g), for example, and Figure 1-(e)). The maps also indicate that while there is no apparent relationship between auto users' job accessibility and commuting times, areas with higher accessibility for transit are likely to be areas with shorter transit commuting times (see Figure 2-(g), for example, and Figure 1-(h)). These results suggest that improving job accessibility for public transit may lead to a reduction in auto usage and transit commuting times. We did not examine causality between job accessibility and commuting behavior and therefore cannot present empirical evidence on whether the level of job accessibility actually affects commuting patterns. The maps' visual presentations, however, help us gain an insight into the possible relationships, providing valuable information for further investigation.

5. Summary and Future Research

This study utilized GIS to measure and examine intra-metropolitan variation in job accessibility by commuting time and mode in the Tokyo metropolitan area. Three-dimensional visualization revealed that job accessibility varied considerably by location and commuting mode. The spatial variability, however, tended to lessen as threshold time lengthened.

The empirical measures of job accessibility provide data useful for examining jobs-housing balance and commuting patterns in future research. This study's accessibility measure is in essence a ratio of jobs to workers and thus indicates the degree of jobs-housing balance. The viability and efficacy of jobs-housing balance policy in managing travel demand is questioned for some American cases (Giuliano, 1991; Giuliano and Small, 1993; Peng, 1997; Wachs et al., 1993), but balancing workplace and residence, combined with improvements in transportation systems, are considered important policy options for Tokyo (see, for example, Bureau of Urban Development Tokyo Metropolitan Government, 2002). One direction of future studies is to examine empirically whether and the extent to which jobs-housing balance has an impact on commuting.
patterns for Tokyo.

Another direction of future research is to investigate the effect of proposed urban and transportation policies on spatial variation in job accessibility and commuting behavior. Examples of proposed planning to achieve reductions in auto usage and commuting duration are promoting city center residence and polycentric urban structure, improving and expanding public transportation systems, and inducing offices and homes to locate in areas with good access to public transportation.

These future examinations are expected to contribute new information valuable for policy debate over jobs-housing balance and commuting behavior.

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References


