CSIS Discussion Paper No. 84

Spatio-Temporal Dimensions of Modal Accessibility Disparity: The Cases of Boston and San Francisco, 1990-2000

March, 2007

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Abstract:
The disparity of accessibility between cars and public transit provides important information about the degree of auto orientation in urban spatial structure. Using 1990 and 2000 spatial data and a geographical information system (GIS), the present study examined the degrees and spatial variations of accessibility disparity between commuting by car and public transit as well as the temporal changes in this disparity in the metropolitan areas of Boston and San Francisco. In both metropolitan areas there was a considerable disparity in job accessibility in a comparison between users of cars and public transit, which turned out to differ substantially by location. Between 1990 and 2000, regional levels of this accessibility disparity lessened in the two metropolitan areas, but the temporal changes in the accessibility disparity varied considerably among different locations within the metropolitan areas. The accessibility disparity decreased in the majority of central areas and in a number of suburban zones near rail stations, whereas the accessibility disparity increased in a number of suburban zones near major highways. Improving accessibility for public transit, relative to that for cars, should be a key strategy for redressing auto-oriented urban spatial structure, an important objective of sustainable development.

1. Introduction

Redressing auto-oriented urban spatial structure is an important objective of sustainable development. Low-density, auto-oriented urban development with excessive automobile dependence has raised a variety of economic, environmental, and social concerns. It is known that urban areas in the US represent spatial structure with strong auto orientation. In 2004, the estimated petroleum consumption in the US was 20.5 million barrels per day, which accounted for 25% of the worlds' petroleum consumption; 67% of the US petroleum consumption was expended by the transportation sector in 2005 (Davis and Diegel, 2006). In 2003, the estimated congestion cost for the US was as much as 63 billion dollars, which was derived from 3.7 billion hours of travel delay and 2.3 billion gallons of wasted fuel (Schrank and Lomax, 2005). In a sprawling, auto-oriented urban spatial structure, people who cannot readily use private vehicles are considerably disadvantaged in accessing opportunities. In recent years, the issue of access equity has received increasing recognition as an integral component of urban and transportation sustainability

(Banister, 2002, 2005; Kawabata and Shen, forthcoming; Richardson, 2005).

Location-based accessibility (referred to simply as accessibility in this study) describes an important dimension of urban spatial structure as it denotes the interrelationship between mobility (performance of transportation systems) and the spatial distribution of opportunities (spatial patterns of land use). When it is differentiated by travel mode, accessibility can principally indicate the degree of auto orientation in urban spatial structure. Previous studies that measured accessibility by car and public transit in US urban areas indicate significantly lower accessibility by public transit than by car (Blumenberg, 2004; Blumenberg and Hess, 2003; Kawabata and Shen, 2006, forthcoming; Shen, 1998, 2001). These studies also indicate considerable spatial variations in accessibility by travel mode; the level of accessibility differs by location within a metropolitan area. However, the degree and intra-metropolitan spatial variation of accessibility disparity between cars and public transit as well as their temporal changes have not yet been sufficiently understood.

This study explores new spatial and temporal dimensions of accessibility disparity between commuting by car and public transit, which provide valuable data for developing strategies to redress auto-oriented urban spatial structure. Specifically, I examine the following two questions. First, to what extent does an accessibility disparity exist when comparing commuting by car and public transit, and how does it vary among locations within a metropolitan area? Second, how have the degree and spatial variation of the accessibility disparity changed over time?

To answer these questions, I utilize spatial data from 1990 and 2000 and a geographic information system (GIS). The first question is addressed by measuring and visualizing the cross-sectional disparity of job accessibility by car and public transit in 1990 and 2000. Differently from most of the related studies, this study demonstrates explicit measures for the accessibility disparity that can be readily compared for diverse areas and different times. The second question is answered by calculating and visualizing temporal changes in the accessibility disparity from 1990 to 2000. In this study, accessibility to jobs (not to hospitals, schools, shops, etc.) is examined because commuting to work is an important reason for travel in daily life, and also because the relevant data are available for a comparison of the accessibility measures. The study areas are the two metropolitan areas of Boston and San

Francisco, which are more auto-dependent than typical urban areas in Europe and the developed parts of Asia but less auto-dependent than typical urban areas in the US.

This paper proceeds by first reviewing literature on the accessibility disparity between cars and public transit in connection with auto-oriented urban spatial structure (section 2). It next describes methods (section 3) and study areas (section 4), then presents empirical results (section 5), and concludes (section 6).

2. Modal accessibility disparity and auto-oriented urban spatial structure

Accessibility is generally interpreted as the ease with which activities may be reached from a given location using a particular transportation system (Morris et al, 1979). Accessibility thereby represents the interrelationship between the performance of transportation systems and spatial patterns of land use, which provides important information about urban spatial structure. Accessibility has been utilized in various research studies, for example, in accessibility comparisons among different population groups, such as by education, income, and occupation (Cervero et al, 1999; Wachs and Kumagai, 1973; Wang, 2003); in examinations of spatial mismatch (Blumenberg, 2004; Hess, 2005; Kawabata, 2003), the linkage between urban spatial structure and travel patterns or behavior (Kockelman, 1997; Levinson, 1998; Shen, 2000), and the sustainability of urban and transportation development (Hemphill et al, 2004; Kwok and Yeh, 2004); as well as in the evaluation of urban and transportation programs (Geurs et al, 2006; Zhang et al, 1998; Zhu and Liu, 2004). Many scholars advocate a broader use of accessibility in urban and transportation research and policymaking (Cervero et al, 1999; Geurs et al, 2006; Handy, 2002; Handy and Niemeier, 1997; Morris et al, 1979; Wachs and Kumagai, 1973).

Accessibility has been measured with various specifications depending on the purpose of its use. Accessibility measurements and their applications are reviewed and summarized by Geurs and van Wee (2004), Handy and Niemeier (1997), Harris (2001), and Morris et al (1979), among others. For examining the disparity of accessibility between cars and public transit in connection with urban spatial structure, (location-based) accessibility for cars versus public transit is particularly useful. Studies that measure accessibility by travel mode for US urban areas indicate considerable differences in accessibility between cars and public transit. One body of research calculated the ratio of the cumulative number of jobs within a 30 minute drive by car to the corresponding number within reach by public transit. The ratio is found to be 1.3-70.2 for welfare recipients in a total of ten neighborhoods in Alameda and Los Angeles Counties in California (Blumenberg and Hess, 2003), 5.2-70.2 for welfare recipients in seven neighborhoods in Los Angeles (Blumenberg, 2004), and 1.7-8.2 for low-income people in a total of 14 neighborhoods in Erie and Niagara Counties in western New York State (Hess 2005). Another body of research measured job accessibility by travel mode, taking into account jobs as well as workers competing for these jobs (or spatial competition). These measures show markedly lower job accessibility by public transit than by car for low-wage workers in Boston (Shen, 1998), less-educated workers in Boston (Shen, 2001), and general workers in Boston and Los Angeles (Kawabata and Shen, 2006) and in San Francisco (Kawabata and Shen, forthcoming). The studies measuring accessibility by travel mode also indicate that the levels of accessibility differ by location within metropolitan areas.

International data suggest that accessibility disparity between cars and public transit is prominent in low-density, highly auto-oriented urban spatial structure. The auto-oriented urban spatial structure is best characterized by US urban areas. Among major cities in Asia, Australia, Europe, and the US, on average, the population density is lowest in US cities (and Australian cities), and the provision of public transit services relative to the provision of roads (transit service kilometers per road kilometer) is also lowest in US cities (Kenworthy et al, 1999). Hong Kong and Tokyo are among the cities with the highest densities and most transit service provisions. For the case of Hong Kong, accessibility is found to be actually much higher for public transit than for cars (Kwok and Yeh, 2004). An international comparison finds that job accessibility by public transit is indeed much lower in Boston and Los Angeles than in Tokyo (Kawabata and Shen, 2006).

The accessibility disparity between cars and public transit can serve as a principal indicator of the degree of auto orientation in urban spatial structure. However, the extent to which this accessibility disparity exists and varies by location within a metropolitan area remains relatively unexplored. Furthermore, the extent to which the degree and spatial variation of the accessibility disparity has changed over time is not well understood. The spatial variation and temporal changes in the degree of the accessibility disparity are valuable data for rectifying auto orientation in urban spatial structure. Such data, for example, help us identify areas with a relatively large or growing accessibility disparity, and also help us evaluate transportation and land use plans, such as public transit improvements, transit-oriented development, and land-use mixing. In developing effective plans, a number of other factors should of course be taken into account. Nonetheless, the spatial and temporal dimensions of the accessibility disparity offer important information that should be worth considering.

3. Methods

The methods used consist of the following three steps: (1) a determination of cross-sectional measures of the disparity of job accessibility by car and public transit in 1990 and 2000; (2) a calculation of temporal-change measures of the accessibility disparity from 1990 to 2000; and (3) an examination of the resulting cross-sectional and temporal-change measures. The following describes each of these three steps.

The first step is carried out by measuring job accessibility by car and public transit in 1990 and 2000 and calculating the disparity of job accessibility between cars and public transit. For this research, the measurement of job accessibility takes into account the mobility of cars versus public transit as well as the spatial distributions of jobs (opportunities) and workers (opportunity seekers). The job accessibility measures are calculated using the following equations, which were developed based on accessibility frameworks proposed by Weibull (1976) and Shen (1998):

$$A_i^{car} = \sum_{j:\, t_{ij}^{car} < t_0} \frac{E_j}{\sum_{k:\, t_{kj}^{car} < t_0} \alpha_k W_k + \sum_{k:\, t_{kj}^{tran} < t_0} (1-\alpha_k) W_k}, \tag{1}$$

$$A_i^{tran} = \sum_{j:\, t_{ij}^{tran} < t_0} \frac{E_j}{\sum_{k:\, t_{kj}^{car} < t_0} \alpha_k W_k + \sum_{k:\, t_{kj}^{tran} < t_0} (1-\alpha_k) W_k}. \tag{2}$$

A_i^{car} and A_i^{tran} represent the measures for job accessibility in residence zone i for car commuters and public transit commuters, respectively; $t^{car}{}_{ij}$ and $t^{tran}{}_{ij}$ are travel times between zone i and zone j by car and public transit, respectively; t_0 indicates a travel time threshold; E_j is the number of civilian jobs in zone j, and W_k is the number of civilian workers (both employed and unemployed) living in zone k; and α_k indicates the rate of car ownership (the proportion of households with cars) in zone k. The resultant job accessibility measure for a zone represents the number of jobs within reach of a given travel time threshold by car (or public transit) for a worker living in that zone. Note that the population-weighted average of job accessibility, combining equations (1) and (2) for an entire metropolitan area, becomes the ratio of the total number of jobs to the total number of workers in the metropolitan area.

The dichotomous approach using the travel time threshold was employed because of its interpretability and practicality; the same travel time threshold, or travel time constraint, generates accessibility measures that are intelligible and comparable among different modes, locations, and times. In this study, three different thresholds of 30, 45, and 60 minutes are examined. Thirty minutes is approximately the average commuting time in 2000 and is therefore considered a representative threshold.[1] In 2000, 45 minutes is about the average commuting time by public transit,[2] and workers with commuting times between 30 and 45 minutes account for 19.1% of commuters in the US nationally (Reschovsky, 2004). Although 60 minutes is approximately twice as long as the previous average commute, workers with commuting times between 45 and 60 minutes comprise a measurable amount, 7.4% in the US nationally (Reschovsky, 2004).

The spatial units of analysis for Boston and San Francisco are the traffic analysis zone (TAZ) for the 986 zone system (a total of 986 TAZs), and the regional travel analysis zone (RTAZ) for the 1099 zone system (a total of 1,099 RTAZs), respectively. These TAZs and RTAZs are the smallest area units for which all the necessary data were available.

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[1] The average commuting time in 2000 is 25.5 minutes for the US nationally (Reschovsky, 2004), and 28.8 and 29.4 minutes for the Boston Primary Metropolitan Statistical Area (PMSA) and San Francisco Bay Area, respectively (shown in Table 1).

[2] The average commuting time by public transit is 47.7 minutes for the US nationally (AASHTO, 2002), and 44.2 and 46.0 minutes for the Boston PMSA and San Francisco Bay Area, respectively (shown in Table 1).

Data on the numbers of workers and jobs and the rates of auto ownership were calculated using data from the Urban Elements of the 1990 and 2000 Census Transportation Planning Packages (CTPPs). The CTPP data for Boston and San Francisco do not include data summarized for TAZs and RTAZs, respectively, but contain data summarized for block groups (BGs) and census traffic analysis zones (CTAZs), respectively. Since BGs and CTAZs are in general smaller than TAZs and RTAZs, the BG-level data were aggregated to determine TAZ-level data for Boston, and the CTAZ-level data were aggregated to determine RTAZ-level data for San Francisco.

Data on peak-hour origin-to-destination (OD) commuting times by car and public transit in 1990 and 2000 (1998 for San Francisco) were provided by the Central Transportation Planning Staff (CTPS) for Boston and the Metropolitan Transportation Commission (MTC) for the San Francisco Bay Area. For Boston, the 2000 data correspond to the 986 zone system, but the 1990 data correspond to a different 790 zone system (an older zone system). Boston's job accessibility measures in 1990 were first calculated for the 790 zone system and then converted to measures that corresponded to the 986 zone system. The OD commuting time data for San Francisco from both 1990 and 1998 correspond to the 1099 zone system. The data from 1998 were the closest to the year 2000 as were available for the 1099 zone system at the time of the analysis. Job accessibility measures from zones that are completely within islands are omitted from the analysis.

The calculated measures for job accessibility by car and public transit are then used to determine the measures for the disparity of job accessibility between cars and public transit. The most straightforward approach to measuring this accessibility disparity would be the ratio of job accessibility by car to job accessibility by public transit. In some zones, however, this ratio generated extremely large and unstable values (over 1,000), which are impractical for comparison. I therefore took a different approach and measured the disparity of job accessibility between cars and public transit in zone *i* (X_i) as follows:

$$X_i = \frac{A_i^{car} - A_i^{tran}}{A_i^{car} + A_i^{tran}} \quad . \tag{3}$$

Equation (3) standardizes the difference between job accessibility by car and job accessibility by public transit to a range from –1 to 1. Figure 1 depicts the measurement of the accessibility disparity. When accessibility is the same for cars and public transit, the disparity measure is zero. When accessibility by car is zero, the disparity measure is –1. Conversely, when accessibility by public transit is zero, the disparity measure is 1. As the disparity measure approaches 1, the accessibility disparity increases.

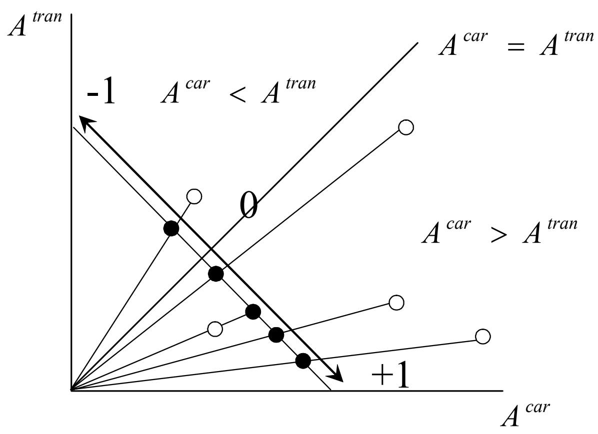


Figure 1. Measurement of accessibility disparity between cars and public transit

The second step is the calculation of temporal changes from 1990 to 2000 in the disparity of job accessibility between cars and public transit. A temporal change in the accessibility disparity in zone *i* (ΔX_i) from time *t0* to time *t1* is measured by $\Delta X_i = X_i^{t1} - X_i^{t0}$. A positive value for this temporal-change measure indicates an increase in the accessibility disparity, whereas a negative value signifies a decrease in the disparity. Note that a larger absolute value for the negative disparity could indicate a greater accessibility disparity, but in this study such a case is considered to indicate less accessibility disparity, given that the disparity measures are positive in almost all zones and also given that greater accessibility by public transit than by car is the desirable condition to achieve sustainable urban spatial structure.

The third step is an examination of the resulting cross-sectional and temporal-change measures. First, I examine the overall regional degrees of the disparity of job accessibility between cars and public transit, along with the temporal changes in this disparity. For this examination, I calculate population-weighted regional averages of the accessibility disparity measures, along with the regional averages of the measures for job accessibility by car and public transit. The population-weighted regional averages for job accessibility by car (A^{car}), job accessibility by public transit (A^{tran}), and the disparity of job accessibility between cars and public transit (X) are calculated as: $A^{car} = \sum_{i=1} (W_i / W) A_i^{car}$,

$A^{tran} = \sum_{i=1} (W_i / W) A_i^{tran}$, and $X = (A^{car} - A^{tran}) / (A^{car} + A^{tran})$, where W_i is the number of civilian workers in zone i, and W is the total number of civilian workers in the whole metropolitan area.

Second, I examine the intra-metropolitan spatial variations and temporal changes in the degree of the accessibility disparity. This examination uses a GIS to plot the cross-sectional and temporal-change measures for the accessibility disparity. The plotted measures are shown with major highways as well as with rail lines and stations to examine whether the degree of the accessibility disparity and the temporal changes in this disparity have any relationship with the locations of these transportation systems. Spatial data on the major highways were extracted from the Census 2000 Topologically Integrated Geographic Encoding and Referencing system/Line Data. Spatial data on rail lines and stations for Boston and San Francisco were provided by the CTPS and MTC, respectively.

4. Study Areas

The study areas are the metropolitan areas of Boston and San Francisco. The Boston metropolitan area used in the study covers all the TAZs in the 986 zone system. The land area considered in Boston covers 7,300 square kilometers, which is larger than the 5,200 square kilometers of the Boston Primary Statistical Area (PMSA) and smaller than the 14,600 square kilometers of the Boston--Worcester—Lawrence Consolidated Metropolitan Statistical Area (CMSA). The San Francisco Bay Area includes the nine counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma. The land area considered in the San Francisco study covers 6,900 square kilometers.

Table 1. Basic population and transportation characteristics

	Boston metropolitan area			San Francisco Bay Area		
	1990	2000	Change from 1990 to 2000	1990	2000	Change from 1990 to 2000
Total population (000) [a]	2,871	3,398	18%	6,024	6,784	13%
Population 16 years and over in labor force (000) [a]	1,620	1,821	12%	3,322	3,535	6%
Means of transportation to work						
% Car [a]	75.6%	76.3%	0.7	81.2%	80.9%	-0.3
% Public transportation [a]	14.2%	13.9%	-0.3	9.5%	9.7%	0.2
Mean travel time to work (min.)						
All modes [a]	24.5	28.8	18%	25.6	29.4	15%
Driving alone [b]	22.9	26.9	17%	23.6	27.3	16%
Public transportation [b]	37.8	44.2	17%	41.2	46.0	12%

Source: [a] US Decennial Censuses, [b] The author's calculation using data from 1990 and 2000 CTPPs.
Note: The Boston metropolitan area for source [a] is the Boston PMSA. Public transportation for the means of transportation to work (from source [a]) includes taxicab and ferryboat, but public transportation for the mean travel time to work (from source [b]) excludes taxicab and ferryboat (i.e., public transportation includes the categories of bus or trolley bus, streetcar or trolley car, subway or elevated train, and railroad).

Table 1 presents the basic population and transportation characteristics of the metropolitan areas of Boston and San Francisco. In 2000, Boston and San Francisco accommodated 3.4 and 6.8 million people, respectively, and 1.8 and 3.5 million workers (persons in the labor force), respectively. Between 1990 and 2000, the population and labor force increased substantially in both metropolitan areas. In Boston and San Francisco, the population grew by 18% and 13%, respectively, and the number of workers increased by 12% and 6 %, respectively.

Both metropolitan areas show considerably high auto dependency. In 2000, the proportions of car commuters in Boston and San Francisco were 76.3% and 80.9%, respectively, while the proportions of public transit commuters were only 13.9% and 9.7%, respectively. Interestingly, between 1990 and 2000 the modal proportions changed only slightly. In Boston, the car share increased by only 0.7 points (from 75.6% to 76.3%) and the public transit share decreased by 0.3 points (from 14.2% to 13.9%). In San Francisco, the car share, although only slightly, *decreased* by 0.3 points (from 81.2% to 80.9%) and the public transit share *increased* by 0.2 points (from 9.5% to 9.7%). In fact, more detailed categories (not shown in the table) indicate that in Boston as well as in San Francisco, the share of rails (including streetcar, trolley car, and subway and elevated rails) increased while the share of buses decreased.[3] These trends contrast with relatively large decreases in the public transit shares observed in both areas during the previous decade. Between 1980 and 1990, the public transit share decreased by 2.3 points (from 12.9% to 10.6%) in the Boston CMSA (Rossetti and Eversole, 1993) and also decreased by 1.9 points (from 11.4% to 9.5%) in the San Francisco Bay Area (MTC, 2002).

In 2000, the average commuting times in the metropolitan areas of Boston and San Francisco were 28.8 and 29.4 minutes, respectively. The data by travel mode, however, indicate that commuting times differ considerably between cars and public transit. In Boston and San Francisco, the average commuting times by public transit (44.2 and 46.0 minutes, respectively) were markedly longer than those by driving alone (26.9 and 27.3 minutes, respectively). During the period from 1990 to 2000, both metropolitan areas experienced substantial increases in travel time to work. The average commuting time in Boston and San Francisco lengthened by 18% and 15%, respectively. The data by travel mode reveal that the average commuting time grew for both cars and public transit. In Boston and San Francisco, the average commuting times by driving alone increased by 17% and 16%, respectively, and the average commuting times by public transit grew by 17% and 12%, respectively.

5. Results

First, I present results for the overall degree of disparity in job accessibility between cars and public transit by region, along with the temporal changes in this disparity. Next, I present results for the intra-metropolitan spatial variations and temporal changes in the degree of the accessibility disparity.

[3] In the Boston PMSA and San Francisco Bay Area, between 1990 and 2000 the proportions of rail commuters increased from 8.5% to 9.4% and from 3.4% to 4.0%, respectively, while the proportions of bus commuters decreased from 5.4% to 4.1% and from 5.9% to 5.4%, respectively.

Table 2 presents the population-weighted regional averages for the measures of the disparity of job accessibility between cars and public transit. For reference, Table 2 also presents the population-weighted regional averages for the measures of job accessibility for cars and public transit. As described previously, the standardized measures of the accessibility disparity range between –1 and 1.

The overall regional measures indicate a considerably large disparity of job accessibility between cars and public transit. The regional measures also indicate surprisingly similar results for Boston and San Francisco. In 2000, the regional measures of the accessibility disparity for the 30-minute threshold were 0.750 and 0.775 in Boston and San Francisco, respectively. The fact that these values are close to 1 indicates a markedly lower job accessibility by public transit than by car. This result is in contrast to the case of Hong Kong, for which a similarly standardized measurement in 1996 was –0.853 (Kwok and Yeh, 2004).[4] The fact that this value is close to –1 denotes a much higher accessibility by public transit than by car. Hong Kong may be an extreme case with predominant public transit systems, but the considerable difference is worth noting.

In both metropolitan areas in this study, the regional measures for the disparity of job accessibility between cars and public transit diminish as the travel time threshold increases, since as the threshold lengthens the regional measures for job accessibility by public transit increase while the regional measures for job accessibility by car decrease or remain stable. This trend suggests that a longer threshold time enables a relatively larger number of public transit users, compared to car users, to access a greater number of jobs. The regional disparity measures for the 60-minute threshold are the smallest among the three threshold times, but all the disparity measures for this longer threshold are still greater than 0.5, indicating large accessibility disparity.

[4] The original measure in Kwok and Yeh (2004) is 0.853. Since their calculation for standardization uses $(A^{tran} - A^{car})/(A^{car} + A^{tran})$ instead of $(A^{car} - A^{tran})/(A^{car} + A^{tran})$, this original measure is equivalent to –0.85 in this study.

Table 2. Regional averages of the measures for job accessibility disparity between cars and public transit and job accessibility for cars and public transit

	Boston metropolitan area			San Francisco Bay Area		
	1990	2000	Change from 1990 to 2000	1990	2000	Change from 1990 to 2000
30 minutes						
Disparity measure	0.826	0.750	-9%	0.845	0.775	-8%
Job accessibility for cars	1.143	1.158	1%	1.028	1.057	3%
Job accessibility for public transit	0.109	0.165	51%	0.086	0.134	56%
45 minutes						
Disparity measure	0.765	0.649	-15%	0.743	0.620	-17%
Job accessibility for cars	1.117	1.134	2%	1.011	1.042	3%
Job accessibility for public transit	0.149	0.241	62%	0.149	0.244	64%
60 minutes						
Disparity measure	0.712	0.578	-19%	0.668	0.534	-20%
Job accessibility for cars	1.101	1.115	1%	1.006	1.035	3%
Job accessibility for public transit	0.185	0.298	61%	0.200	0.314	57%

It is interesting to find that between 1990 and 2000, the disparity of job accessibility between cars and public transit at the regional level lessened for both Boston and San Francisco. The regional disparity measures for the 30-minute threshold, for example, decreased by 9% (from 0.826 to 0.750) in Boston and 8% (from 0.845 to 0.775) in San Francisco. These decreases were the result of greater improvements in the regional measures for job accessibility by public transit compared to job accessibility by car. The magnitude of the decreases is greater for longer thresholds. The regional measures of the accessibility disparity with the 60-minute threshold, for instance, declined by 19% (from 0.712 to 0.578) in Boston and 20% (from 0.668 to 0.534) in San Francisco.

The cross-sectional and temporal-change measures for the disparity of job accessibility between cars and public transit can be plotted on maps. Figures 2 and 3 assist in visualizing the measures with the 30-minute threshold for the metropolitan areas of Boston and San Francisco, respectively. Each figure presents four maps: (a) cross-sectional measures for the disparity of job accessibility between cars and public transit in 2000 (with major highways); (b) cross-sectional measures for the accessibility disparity in 2000 (with rail lines and stations); (c) temporal-change measures for the accessibility disparity from 1990 to 2000 (with major highways); and (d) temporal-change measures for the accessibility disparity from 1990 to 2000 (with rail lines and stations). Maps for the measures with the 45- and 60-minute thresholds are not presented but were examined.

Figures 2a, 2b, 3a, and 3b indicate that the degrees of the disparity of job accessibility between cars and public transit differ substantially among locations within the metropolitan areas. In general, the accessibility disparity is relatively small around urban core areas, but relatively large in suburban areas.[5] The majority of zones in the central business districts in Boston, downtown San Francisco, and downtown Oakland exhibit disparity measures of 0.5 or less (relatively low accessibility disparity). This result is reasonable given that these areas are served by comparatively well-developed public transit systems. The majority of suburban zones, on the other hand, display disparity measures greater than 0.5. Of particular note is the fact that many suburban zones show disparity measures greater than 0.9 (extremely high accessibility disparity). A number of such suburban zones with extremely high accessibility disparity are found near major highways, while a number of suburban zones with lower accessibility disparity are observed near rail stations. These trends are consistent when examined with the 45- and 60-minute thresholds.

[5] The negative disparity measures in 2000 in the western and eastern zones of the San Francisco Bay Area are unnatural. This result is due to the zones' scarce population and relatively large size which destabilized job accessibility measures. This is a limitation of using TAZs or RTAZs. Since these zones are sparsely populated, however, the result does not significantly distort the population-weighted regional measures.

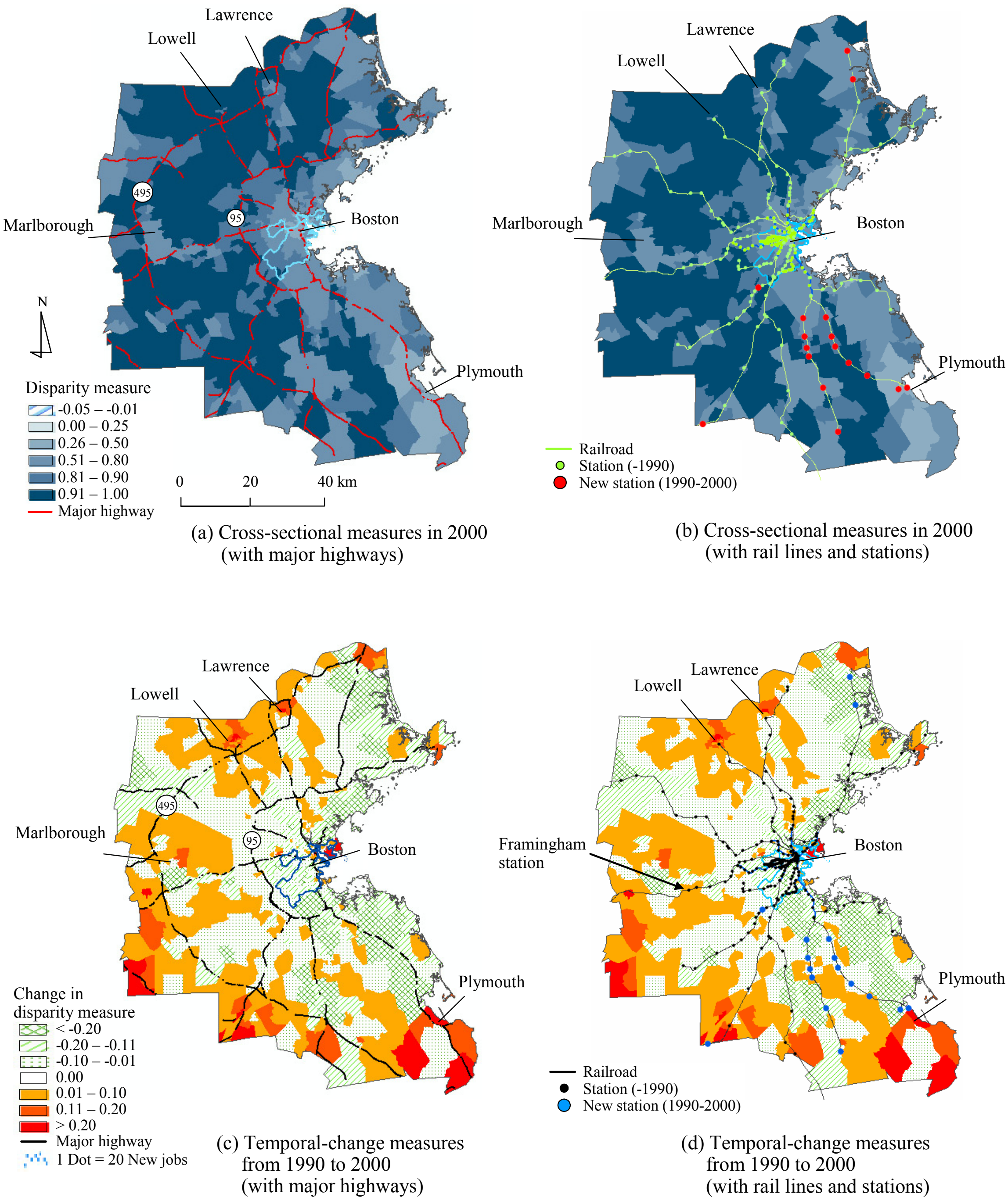
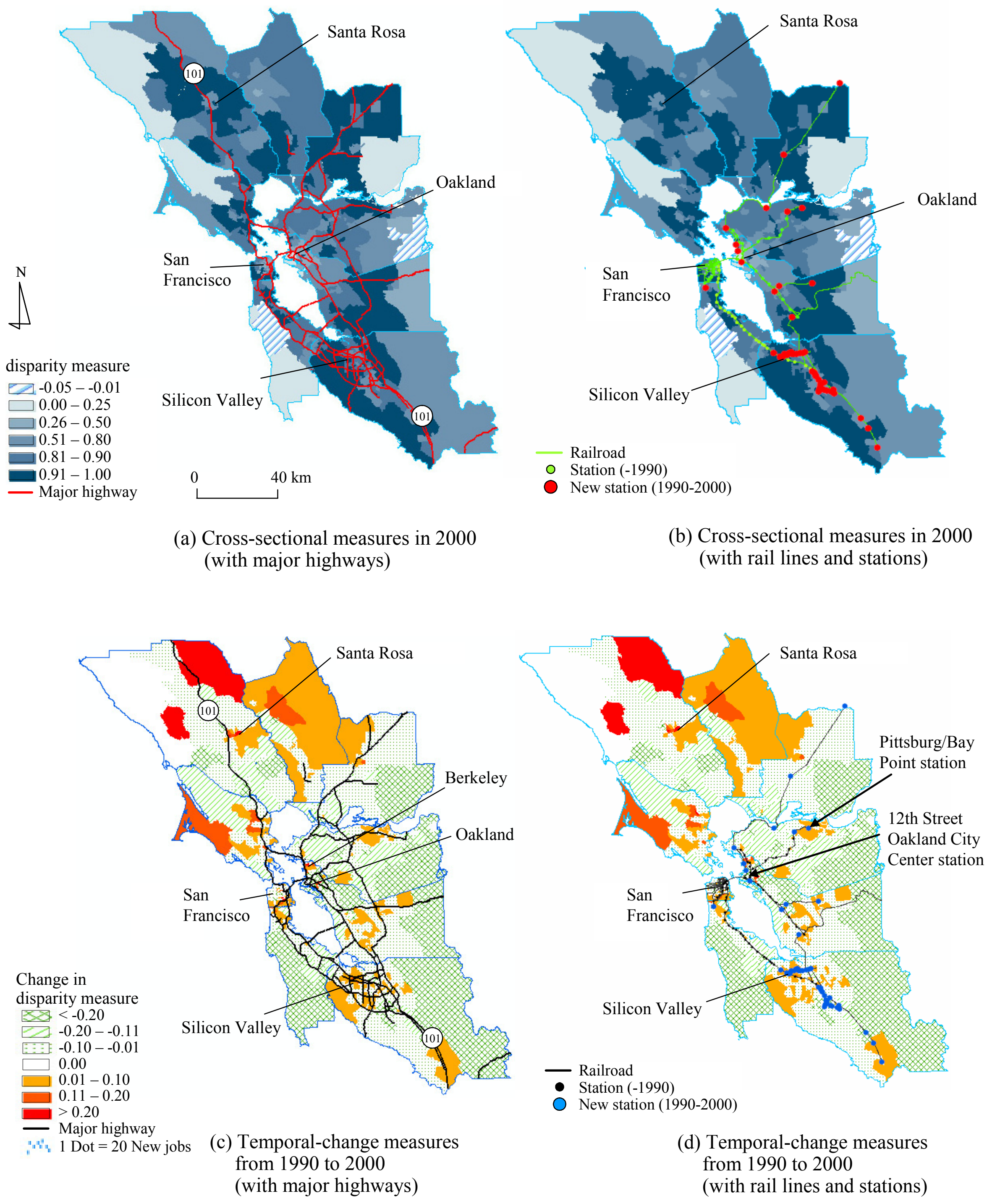


Figure 2. Disparity of job accessibility between cars and public transit in the Boston metropolitan area (30 minutes)



(a) Cross-sectional measures in 2000 (with major highways)

(b) Cross-sectional measures in 2000 (with rail lines and stations)

(c) Temporal-change measures from 1990 to 2000 (with major highways)

(d) Temporal-change measures from 1990 to 2000 (with rail lines and stations)

Figure 3. Disparity of job accessibility between cars and public transit in the San Francisco Bay Area (30 minutes)

Figures 2c, 2d, 3c, and 3d illustrate the temporal changes in the disparity of job accessibility between cars and public transit from 1990 to 2000. A negative value indicates a decrease in accessibility disparity, and conversely, a positive value indicates an increase in accessibility disparity. The maps reveal that the temporal changes in the degree of accessibility disparity vary considerably by location within the metropolitan areas. It is a favorable finding that a large number of zones experienced a decrease in accessibility disparity. However, there are also zones that experienced an increase in accessibility disparity. Zones with either decreased or increased accessibility disparity are widely scattered within the metropolitan areas, but the following three patterns are observed in general.

The first pattern is that the disparity of job accessibility between cars and public transit lessened in the majority of central zones. In Boston, the great majority of zones inside and around Route I-95 show diminished accessibility disparity. In San Francisco, most zones around downtown San Francisco and downtown Oakland indicate decreased accessibility disparity. These results suggest that dependence on public transit increased in areas where dependence on public transit had been known to be relatively high. Indeed, MTC (2004) reports that there were noticeable increases in public transit commuting to downtown San Francisco and downtown Oakland between 1990 and 2000. The public transit shares of commuting to downtown San Francisco and downtown Oakland increased from 46.6% to 49.0% and from 20.2% to 24.1%, respectively, and the number of public transit users commuting to downtown San Francisco and downtown Oakland grew by 18% and 45%, respectively.

The second pattern is that the disparity of job accessibility between cars and public transit increased in a number of suburban zones near major highways. In Boston, there was also an increase in a number of suburban zones without commuter rails nearby. Relatively large increases are found, for example, in areas around Route I-495 in Boston and in some parts of Silicon Valley and northern areas in San Francisco. These results suggest that reliance on public transit deteriorated in areas where reliance on public transit had been known to be relatively low, in contrast to the trend for the central areas.

The third pattern is that the disparity of job accessibility between cars and public transit lessened in many suburban zones near rail stations, whether existing or newly-developed. In Boston, many of the suburban zones with decreased accessibility disparity are found around rail stations. In San Francisco, many suburban zones around rail stations experienced lessened accessibility disparity. During the 1990s, both metropolitan areas developed a fairly large number of new rail lines and stations. In Boston, the regional commuter rail system opened the Middleborough/Lakeville Line and Providence/Stoughton Line in the southern suburbs, along with a number of stations. In San Francisco, the Altamont Commuter Express and Amtrak Capitol Corridor began operation, and quite a few stations were added to the regional public transit systems, including the Bay Area Rapid Transit (BART), Caltrain, and Santa Clara Valley Transportation Authority. Accordingly, the accessibility disparity diminished in many zones around these newly-opened rail lines and stations, suggesting a heightened reliability for suburban public transit. Moreover, MTC (2004) documents that during the 1990s, San Jose, which developed new light rail extensions and stations, attracted a substantial number of riders for public transit. Between 1990 and 2000, the public transit share of commuting to jobs in downtown San Jose increased from 4.7% to 7.2%, and the number of workers commuting by public transit to downtown San Jose rose by 60%.

It has to be noted that in some suburban zones near rail stations, the disparity of job accessibility between cars and public transit increased with the 30 minute threshold, but in many of such zones the accessibility disparity decreased with the longer thresholds of 45 and 60 minutes. This result may suggest that with longer travel time thresholds, suburban residents who take public transit to commute to work became more likely to attain jobs in central areas or suburban employment centers than those who use cars for commuting.

The fact that the accessibility disparity for suburban residents increased for shorter travel times but decreased for longer travel times may largely have resulted from an increase in road congestion, improvements in public transit, or both. An example is the area around Framingham Station (which already existed in 1990) in the western suburbs of Boston (see Figure 2d). In zones surrounding this station, the accessibility disparity increased with the 30-minute threshold but decreased with the 45- and 60-minute thresholds. Since one way travel time between Framingham Station and Back Bay Station/South Station in downtown Boston by commuter rail is approximately 30-50 minutes (MBTA 2007), it is likely that residents in the Framingham Station area can reach highly-concentrated jobs in downtown Boston within 45 to 60 minutes by commuter rail. In this case, the decreases in the accessibility disparity for the longer thresholds might largely reflect an increase in congestion, which impedes the mobility of cars.

Another example is the area around Pittsburg/Bay Point Station (which opened in 1996) in the eastern suburbs of San Francisco (see Figure 3d). In zones surrounding this station, the accessibility disparity increased with the 30-minute threshold but decreased with the 45- and 60-minute thresholds. Since one way travel time between Pittsburg/Bay Point Station and 12th Street Oakland City Center Station (downtown Oakland) by BART is approximately 40 minutes (BART 2007), it is likely that as of the station's opening in 1996, residents in the Pittsburg/Bay Point Station area became able to access jobs in downtown Oakland within 45 to 60 minutes using BART. In this case, improvements enhancing the mobility of public transit might have played a major part in the decreases in the accessibility disparity with the longer thresholds.

6. Conclusion

This empirical study has examined the spatial and temporal dimensions of accessibility disparity between car and public transit commuting in the metropolitan areas of Boston and San Francisco. The results for the two metropolitan cases were surprisingly similar.

The empirical measures for the disparity in job accessibility between cars and public transit indicated considerably lower job accessibility by public transit than by car. It was a favorable finding, however, that between 1990 and 2000 the accessibility disparity at the regional level decreased in both metropolitan areas. Such temporal decreases in the accessibility disparity may be related to the fact that the public transit shares of commuters remained largely unchanged between 1990 and 2000 (Table 1), in contrast to the public transit shares themselves that apparently declined during the previous decade as noted earlier.

Within the metropolitan areas, there were considerable spatial variations and temporal changes in the disparity of job accessibility between cars and public transit. Major findings can be summarized as follows. First, in general the disparity of job accessibility between cars and public transit was relatively low in urban core areas but relatively high in suburban areas. In fact, extremely high accessibility disparity (disparity measures greater than 0.9) was found in a large number of suburban zones. Second, between 1990 and 2000 the accessibility disparity lessened in the majority of zones in central areas with relatively well-developed public transit systems and also in many suburban zones near rail stations, whether existing or newly-developed. Moreover, between 1990 and 2000 the accessibility disparity grew in a number of suburban zones near major highways, and in Boston it also grew in a number of suburban zones without nearby commuter rails.

Accordingly it is suggested that the provision of public transportation systems can lessen the disparity of accessibility between cars and public transit not only in central areas but also in suburban areas. It is also suggested that the improvement of accessibility for public transit relative to that for cars is important in rectifying auto-oriented urban spatial structure. Although overall regional disparity of job accessibility between cars and public transit mitigated during the 1990s, the accessibility disparity is still considerably large. The augmentation of accessibility for public transit relative to that for cars should be a key strategy for redressing auto-oriented urban spatial structure, an important objective of sustainable development.

The empirical measures from this study can be used, for example, to identify areas with a growing disparity of job accessibility between cars and public transit as well as increasing job opportunities, which can be considered priority areas for public transit improvements.[6] The empirical measures can also be used to examine the extent to which public transit improvements and land use changes would decrease the disparity of job accessibility between cars and public transit. Comprehensively evaluating conceivable scenarios is beyond the scope of this paper, but several cases can be demonstrated. Suppose, for instance, public transit systems

[6] Such zones are found, for example, in Lowell, Marlborough, Plymouth, and Taunton in the Boston metropolitan area and in Berkeley, Santa Rosa, and some Silicon Valley cities, including Mountain View and Sunnyvale, in the San Francisco Bay Area (see Figure A1 in Appendix).

are improved in the city of Lawrence, part of which actually experienced an increase in the disparity of job accessibility between cars and public transit. If the improvement in public transit systems reduces OD transit commuting time by 10% in each origin zone in the city of Lawrence, the overall accessibility disparity for this city would decrease by 3.7% (from 0.856 in 2000 to 0.824). If, besides this public transit improvement, the number of jobs in each zone in the city grows by 10%, the overall accessibility disparity for the city would decline further, by 4.6% (from 0.856 in 2000 to 0.817).

This study examined the cases of Boston and San Francisco, which have relatively low auto dependency by US standards but relatively high auto dependency by international standards. Auto orientation in urban spatial structure is dominantly strong in the US, whereas auto orientation is growing in many other parts of the world (Giuliano et al, 2004). One direction of future research will involve an examination of other domestic and international urban areas and a comparison of the results. Another direction of future research will entail an examination of whether decreases in accessibility disparity between cars and public transit significantly augment public transit use. Such future research will provide more comprehensive data to help develop strategies to redress auto-oriented urban structure, not only for advanced nations but also for developing countries.

Acknowledgements

This research was supported by research grants from the Japan Society for the Promotion of Science and the Asahi Glass Foundation. The author thanks Masahiro Hachimori, Yuzo Maruyama, and Qing Shen for their helpful comments, and Clinton Bench, Thomas J. Humphrey, Charles Purvis, and Paul Reim for their assistance with obtaining transportation data.

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Appendix

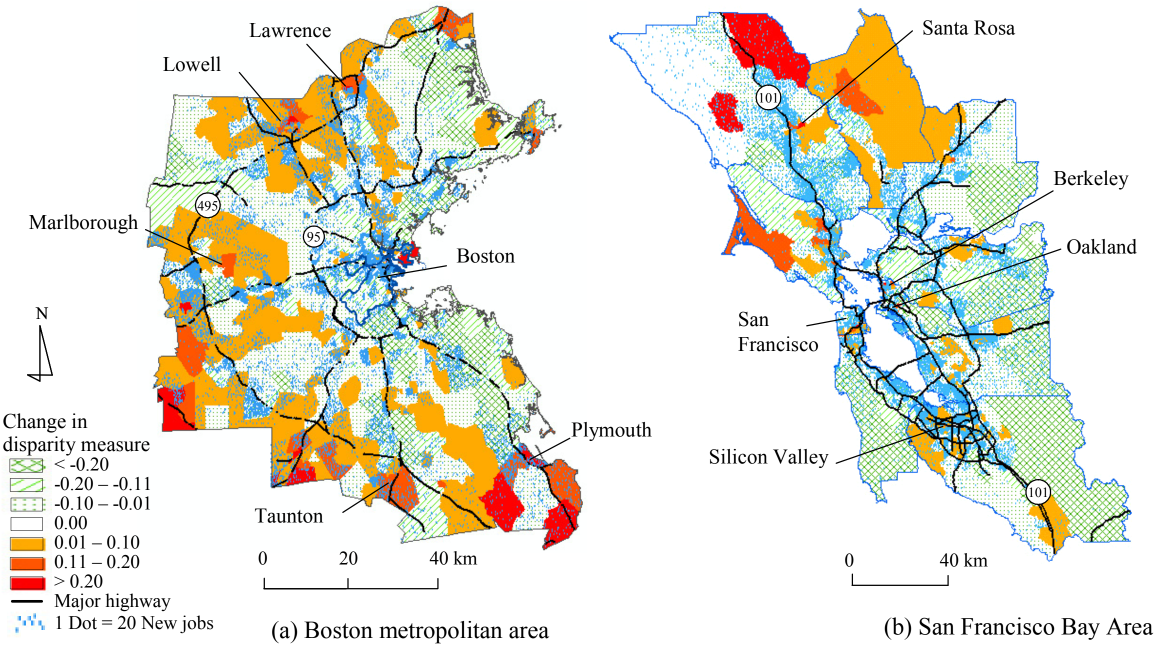

Figure A1. Changes in disparity of job accessibility between cars and public transit and new jobs from 1990 to 2000 (30 minutes)