Metropolitan Accessibility and Transportation Sustainability:

Comparative Indicators for Policy Reform

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Summary

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Description and Objective of Research

Transportation planning and policy have traditionally been evaluated with mobility-based indicators. These metrics implicitly treat ease of movement—often interpreted as roadway travel speeds—as definitive indicators of success in transportation policy. This perspective has led to the development of highway-intensive metropolitan areas in which vehicle-miles traveled per capita are high. Apart from its environmental implications, this perspective neglects the insight that the purpose of travel is not movement but access; that is, the demand for travel is derived from people's desires to reach destinations. Movement is only one means to achieving accessibility; the other two are proximity (when people are near to their destinations they can reach them without much movement) and remote connectivity (e.g., via phone or Internet). The current study seeks to promote a shift in transportation policy from mobility-centered to accessibility-centered evaluation and practice by developing and estimating accessibility indicators that can be compared both within and between metropolitan areas.

Summary of Findings

Accessibility is most commonly studied and measured within the context of a single metropolitan region. By contrast, this study applies metrics of accessibility (for work, non-work, by auto and transit) that incorporate both mobility and proximity to 38 of the largest 50 U.S. metropolitan areas. This cross-sectional analysis allows both intermetropolitan comparison (of accessibility overall and of the equity of its distribution) and assessment of the determinants of metropolitan accessibility.

The two components of accessibility analyzed here—mobility and proximity—exist in tension with each other: places with rapid surface travel are usually places where origins and destinations are far apart; places with many origins and destinations in close proximity are places where travel tends to be slow. For this reason, it is not apparent which urban forms offers greater accessibility: those with spread-out land uses and more rapid travel, or more compact arrangements in which travel is slower. There are good theoretical reasons to expect that surface travel speeds are all-important in determining accessibility outcomes and that anything that interferes with surface travel speeds—including denser metropolitan development—might degrade accessibility.

Empirical results presented here suggest the opposite: more compact metropolitan regions offer greater auto accessibility even if their travel speeds are somewhat slower. In other words, the proximity effect of density dominates any associated degradation in travel speeds. This suggests that reform of policies that spur low-density, auto-oriented development can yield transportation benefits in terms of increased metropolitan accessibility.

The report also develops indicators for assessing the equity of the distribution of accessibility between individuals within a region. Indicators developed here capture accessibility distributions across dimensions of income, race, and car ownership. Even with a given accessibility distribution by auto and by transit, the equity of the accessibility distribution also depends on the location of carless households within a metropolitan region; indicators are also developed to capture this effect.

Conclusions

The study suggests several implications for transportation and environmental planning practice. It demonstrates the feasibility of accessibility indicators in intermetropolitan comparison. Transportation outcomes are regularly evaluated between regions; putting accessibility within this intermetropolitan framework can assist in the transfer of accessibility metrics to professional practice. The metrics extend both to the measurement of accessibility overall and to the analysis of the equity of its distribution. The diffusion of accessibility metrics in transportation planning practice will be greatly assisted by the standardization (and standardized reporting) of data on the part of metropolitan planning organizations, particularly the outputs of metropolitan travel models.

Implications of a shift from mobility- to accessibility-based transportation practice are far reaching. Currently land-use regulations are frequently deployed to lower development densities, often in an attempt to forestall roadway congestion. This practice, informed by mobility-based transportation thinking, has the effect of reducing the population that is able to live in or otherwise use high-accessibility zones. Results presented here suggest that such practice can degrade accessibility for the population overall; paradoxically, a policy implemented ostensibly to improve transportation outcomes will have degraded accessibility. By contrast, an accessibility-based transportation and land-use planning practice would simultaneously create high-accessibility areas (both by auto and transit modes) and facilitate their use by significant shares of the population.

Publications/Presentations

Grengs, Joe, Jonathan Levine, Qing Shen, and Qingyun Shen. (2010). Intermetropolitan Comparison of Transportation Accessibility: Sorting Out Mobility and Proximity in San Francisco and Washington, DC. *Journal of Planning Education and Research*, 29(4), 427-443. (Winner of the Chester Rapkin award for best paper of the year in the Journal of Planning Education and Research)

Metropolitan Accessibility and Transportation Investment. Arie Shachar Memorial Lecture, Institute for Urban and Regional Studies, Hebrew University of Jerusalem, 2010.

Transportation Accessibility. Lecture to the Graham Environmental Sustainability Institute External Advisory Committee, University of Michigan, 2010

Expert in Residence. Department Sustainable Cities Initiative, University of Oregon, Eugene. 2010.

Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform. "Transportation at McGill" lecture series. School of Urban Planning, McGill University, Montreal 2010.

Keynote Address, From Mobility to Accessibility: A New Policy for Advancing Social Equity. Transportation Research and Education Conference, Michigan Center for Advancing Safe Transportation throughout the Lifespan, 2010.

Invited Lecturer, Challenges in Sustainable Transportation. Better Living Using Engineering Laboratory, University of Michigan, 2010.

Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform. Instituto Superior Tecnico, Lisbon, Portugal, 2009.

Intermetropolitan Comparison of Transportation Accessibility: Which Regions are Most Accessible? Paper presented at the annual meeting of the Association of Collegiate Schools of Planning, Crystal City, VA, 2009.

Keynote Address, Transport Chicago Conference, 2008.

Accessibility and Mobility: Comparative Indicators for Policy Reform. Environmental Protection Agency, Washington DC, 2008.

Invited Lecturer, Ben Gurion University, Sde Boqer, Israel, 2008. "Transportation Accessibility and Metropolitan Sustainability."

Invited Lecturer, University of Iceland, Reykjavik, 2008. "Transportation Accessibility and Metropolitan Sustainability."

Invited Lecturer, Instituto Superior Tecnico, Lisbon, Portugal, 2007. "Transportation Accessibility and Metropolitan Sustainability."

Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform. Cities and Climate Change: Responding to an Urgent Agenda. Conference held in Marseille, France, 2009.

Urban Transportation and Social Equity: Three Transportation-Planning Paradigms that Impede Policy Reform. Planning for/with People: Looking Back for the Future. Conference held in Haifa, Israel, 2009.

Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform. Presented at the conference of NECTAR (Network for Communication and Transportation Activity Research), Rotterdam, 2008.

Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform. Environmental Protection Agency Grantees' Conference, Washington DC, 2008.

Accessibility and Mobility in Transportation Planning. Roundtable. Presented at the meeting of the Association of Collegiate Schools of Planning, Milwaukee, WI 2007.

Supplemental Keywords

Transportation, land use, evaluation

Relevant Web Sites

http://www.umich.edu/~umaccess/

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Accessibility and Mobility in Transportation Planning

"An experienced Australian traveler once said that on business trips to Australian cities he could reckon to make four meetings in a day," writes Thomson (1977:48). "In Europe he could manage five; in the United States he could manage only three." The reason behind the variations in this traveler's itineraries was not an American propensity for long meetings, or the speed of travel in American cities, which is in any case faster than in Western Europe or Australia (Kenworthy and Laube 2002). Instead, his schedules were determined by the great distances—and hence long travel times—separating his business contacts in metropolitan areas of the United States. What the traveler wanted was interaction in the form of personal contact with the people with whom he did business. The speed with which he was able to travel was relatively unimportant to him; much more central was the amount of interaction he could accomplish in a given time.

This traveler was unwittingly expressing a view of transportation policy based in accessibility[1], in contrast to the mobility-centered view so dominantly reflected in current policy and in the physical form of the built environment in metropolitan areas in the United States and many countries around the world. This mobility-oriented view extends to the metrics by which transportation systems are assessed. When evaluating the performance of a transportation system, the fundamental criterion for success has long been faster vehicle operating speed (Ewing 1995). Common indicators include delay per capita, dollars wasted while waiting in traffic (Schrank and Lomax 2007) and highway level-of-service (U.S. Department of Transportation 2002; Transportation Research Board 1994; Edwards 1992). This mobility-based perspective of transportation policy dominates the view of the general public as well. The widely publicized congestion measures that routinely appear in newspapers nationwide when the Texas Transportation Institute publishes its annual Urban Mobility Report (Schrank and Lomax 2007)

[1] In other contexts, "accessibility" focuses on the needs of people with disability. The concept is used more broadly here.

have helped to elevate the alleviation of traffic congestion to a top public policy priority. Under all such mobility-based evaluation measures, planners, engineers, and the general public deem rapid movement as definitive success.

Yet an axiom of modern transportation planning is the notion that the demand for transportation is “derived” (Meyer and Miller 1984); that is, people rarely consume transportation for the pleasure of movement per se, but rather travel in order to reach opportunities available at destinations. This fundamental understanding is an underpinning of travel demand analysis, which models transportation flows based on the arrangement of land use patterns across a region (Mitchell and Rapkin 1954). Despite some speculation that some market segments may view movement as an end in itself (Salomon and Mokhtarian 1998), the "derived demand" hypothesis remains the consensus of the field, a view supported by the preponderance of empirical evidence.

Apart from its role in land-use based travel demand analysis, the derived-demand assumption has another important implication, which transportation policy has too rarely confronted. If the purpose of transportation is not movement but access, then increased mobility is desired only to the extent that such a change also increases accessibility over the longer run. A mobility improvement that is associated with degraded accessibility would leave people with less time and money with which to interact with their destinations and for that reason cannot be viewed as a transportation-policy success. For this reason, evaluations of transportation outcomes based in mobility alone suffer from a distinct logical flaw.

Pursuit of congestion relief through added transportation capacity can induce destinations to move farther and farther apart (Transportation Research Board, 1995). A paradox can thus arise: increased mobility can be associated, over the long run, with more time and money spent in travel, rather than less. Travel to more remote shopping or work locations might be accomplished at a high speed, but the spread of these destinations can demand more travel than in more compact and clustered urban arrangements in which travel is slower. Thus the “derived” nature of transportation demand implies a rejection of "mobility" or congestion relief per se as an independent goal for transportation policy. The goal is more properly specified as accessibility, which has been defined as the “potential of opportunities for interaction” (Hansen 1959, 79) or the “ease of reaching places” (Cervero 1996, 1). Mobility, by contrast, is simply the “ease of movement.” Where destinations are nearby, high accessibility can be provided even with low mobility (as the Australian business traveler found in the compact cities of Europe); conversely, where origins and destinations are spread broadly, even great mobility does not ensure high accessibility. Mobility is one means to accessibility; other means would include remote connectivity (e.g., via Internet or other electronic means), and proximity (Figure 1).

But mobility and proximity exist in tension with each other: places with many origins and destinations near one other tend to be places where surface transportation is slow; conversely, areas of rapid surface travel tend to be areas where origins and destinations are more spread. It is thus not immediately apparent which urban forms offer higher accessibility: areas of rapid surface travel and little proximity, or areas offering high proximity of origins and destinations but slower travel. Accessibility impacts would be the result of the net effect of speed and distance change as one moves from one urban form to the other.

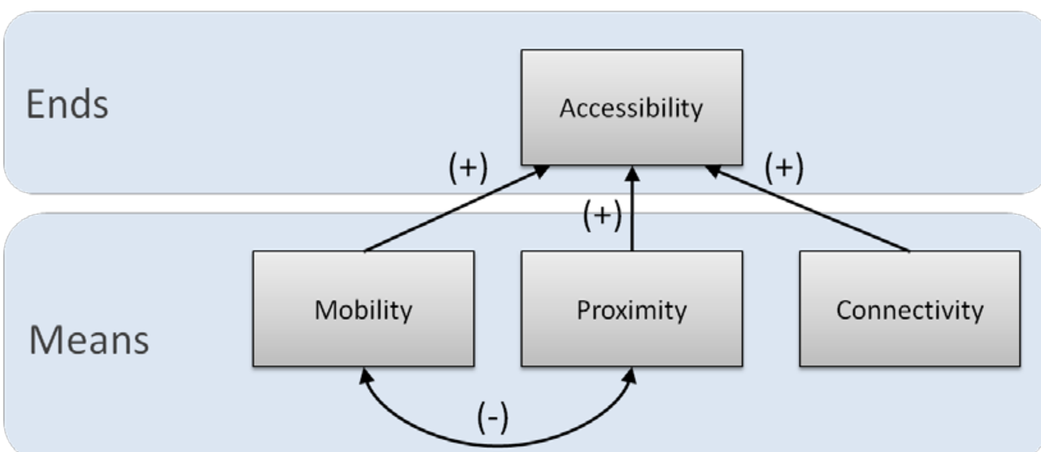


Figure 1: Relationships among mobility, proximity, connectivity, and accessibility

Comparisons could be on the basis of the same region or regions over time (e.g., Grengs 2004) or between regions in a cross-sectional analysis. This study compares accessibility across metropolitan regions using the cross-sectional approach. One consideration in this design was data availability: outputs of regional travel models (needed inputs to the study’s analyses) are rarely archived, and generating an ample basis for comparison would be difficult. The second consideration pertained to sources of variation. Metropolitan regions grow incrementally, so their urban form does not change radically from one decade to the next. For this reason, a time-series comparison would have limited variance between observations. By contrast, a cross-sectional comparison makes use of existing variance in urban form between metropolitan areas in order to infer relationships with accessibility outcomes. This study takes the latter approach, and estimates accessibility metrics for 38 of the largest 50 metropolitan regions in the United States.

Nearly all empirical research measuring accessibility to date has been focused on case studies of single metropolitan regions (e.g., Levinson et al 2010, Benenson et al 2010, Scott and Horner 2008, Chen 2008, Cheng et al 2007). This study seeks to support policy reform by developing and estimating measures of accessibility that enable a meaningful comparison between multiple metropolitan areas of the United States. The indicators, which can be analyzed both within and between regions, can help gauge the progress of policy on infrastructure and the built environment.

Accessibility vs. Travel Behavior in Transportation Policy Evaluation

One broadly used evaluation approach in transportation and land-use planning seeks to link individuals' travel behavior to the characteristics of the built environment. Scholars working under this approach hypothesize that areas that are developed in a fashion that is compact, mixed use, and safe and amenable for pedestrians and cyclists will influence people's travel behavior toward less driving, and more transit use, cycling, and walking. Ancillary benefits in physical activity, health, and obesity mitigation have also been asserted. If this causal link can be established, these scholars reason, then policy makers will have the support they need for advancing policies to promote compact cities and regions. Planning for "smart growth" would enjoy a legitimacy rooted in the proven mitigation of environmental and other harms.

Much research at the nexus of transportation and environmental quality since 1970 has in fact focused on the potential travel-behavior impacts of various urban forms (e.g, Lansing et al. 1970, Cervero 1989, Boarnet and Crane 2001). The hypotheses tested generally focus on the capacity of compact urban forms to reduce auto use and increase its alternatives, including walking, cycling, and transit use—particularly in comparison to auto-oriented suburban development of the post-WWII era.

At a macro level, there is much reason to view metropolitan densities and transportation infrastructure as significant shapers of travel behavior. In the United States, vehicle-miles traveled per capita are negatively associated with overall urbanized-area densities (Figure 2) and positively associated with a region's freeway intensity (Figure 3), defined as freeway lane-miles per 10,000 residents. But these macro-level analyses are difficult to translate into policy to guide urban change, since such change happens incrementally. For example, one might predict that if densities in the Atlanta urbanized area were to increase to that of Washington, DC, there would be a concomitant fall in Atlantans' vehicle miles traveled per capita. But that prediction, even if true, would leave unanswered several important questions: are the economic conditions of metropolitan Atlanta such that its overall density could in fact be increased to that of metropolitan Washington D.C? Moreover, such change, if it were to happen, would occur in a development-by-development fashion. In the context of a lower-density metropolitan region, what would the impact of a handful of higher-density, transit-accessible developments be on the travel habits of their residents?

In this vein, urban-form and travel-behavior studies have attempted to mimic the impact of incremental change: what difference does it make if such change occurs in a pedestrian-and-transit-oriented fashion versus auto-oriented? But the connection has proven surprisingly elusive. Experimental designs—under which a randomly selected control group would live and travel in auto-oriented regions, and an experimental group might inhabit compact neighborhoods—are generally impossible in this arena. Without this experimental capacity, researchers have relied on quasi-experimental designs in which real-world variability is controlled statistically. As a consequence, conclusive evidence on the relationship has been hard to come by, and policy makers are, in effect, advised to await further study before taking action. An early study (Gilbert and Dajani 1974, 275) concluded that "the extent to which urban form influences transportation energy usage and the possibilities for using transportation policy as a land use control…are complicated and perhaps not subject to definitive answers, and thus we are led to the all-too common conclusion that more research is needed." After nearly three decades of increasingly sophisticated research using ever improved datasets, statistical methods, and techniques for geographic analysis, Boarnet and Crane (2001, 14) reached nearly identical results: "Our conclusion is not that urban design and transportation behavior are not linked, or that urban design should never be used as transportation policy. Rather, we conclude that we know too little about the transportation aspects of the built environment…."

While the search for greater knowledge in the land-use/travel-behavior connection will continue unabated, policy towards land-use and transportation, sustainability, and the built environment will be made for the foreseeable future under conditions of distinct uncertainty on the precise nature of the urban-form/travel-behavior relationship. Policy makers and public officials do not have the option of waiting until behavioral science provides reasonable certainty on how the built environment affects travel, because policymaking in the realm of transportation and the built environment is continuous and unavoidable: transportation systems are planned and built, land is regulated and developed, and the built environment—with all its implications for sustainability—is produced. Moreover, the built environment is rapidly regenerating and expanding; of the buildings in existence in the United States in the year 2030, 50% will have been built after 2000 (Nelson 2006). Notwithstanding the uncertainty in the science of travel behavior, the relationships among transportation, the built environment, and sustainability are too vital and urgent for policy to ignore.

Moreover, it is not clear that increasingly precise modeling of the connection between urban form and travel behavior will assist greatly in the problems of transportation and land-use policy making. This is for three principal reasons. First, as described above, prospects for anything approaching a scientific consensus on the matter seem remote. Secondly, with current regulations predominantly lowering densities and separating land uses (Levine 2006), scientific proof of the urban-form/travel-behavior connection would hardly seem to be a prerequisite for choice-expanding policy reform. And finally, reduction in travel per se—even reduction in driving—is not an independent goal of transportation policy. Some circumstances—e.g., recession-induced travel cutbacks, center-city decline—may be considered problems even if they reduce driving. Others—e.g., programs to assist poor people to acquire cars, or development that puts origins and destinations near to each other (Crane 1996)—may be considered successes even if they increase auto use.

The policy goal is better specified as reductions in the environmental impact of the transportation system paired with maintenance and even enhancements in people's accessibility overall and the fairness of its distribution. Viewed in this way, the high vehicle-miles traveled (VMT) per capita travel patterns in low-density metropolitan regions such as Charlotte, Houston, and Oklahoma City (Figure 2) present an ambiguity: these patterns alone do not reveal whether such areas are high- or low-accessibility regions. It may be that residents of these regions are able to reach more destinations than their counterparts in higher-density, lower-VMT regions. Alternatively, the high VMT per capita of these regions may be a product of their residents seeking to meet the ordinary needs of an ordinary day in an environment in which origins and destinations are unusually remotely spread.

Intermetropolitan comparison of accessibility can help resolve these ambiguities. By examining both the urban-form characteristics and accessibility outcomes of multiple metropolitan regions, this study seeks to infer those spatial attributes that lead to higher accessibility regions.

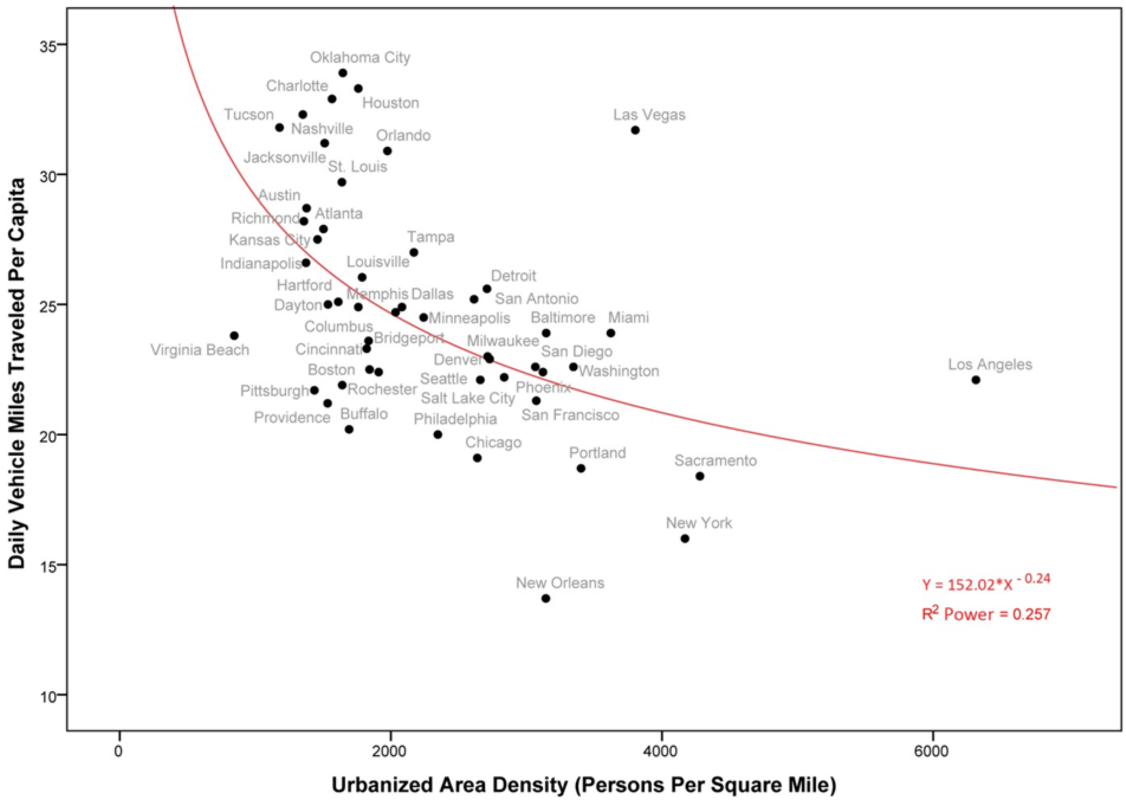


Figure 2: Daily Vehicle Miles Traveled by Urbanized Area Density, Largest 50 US Urbanized Areas. (Source: US Department of Transportation 2008)

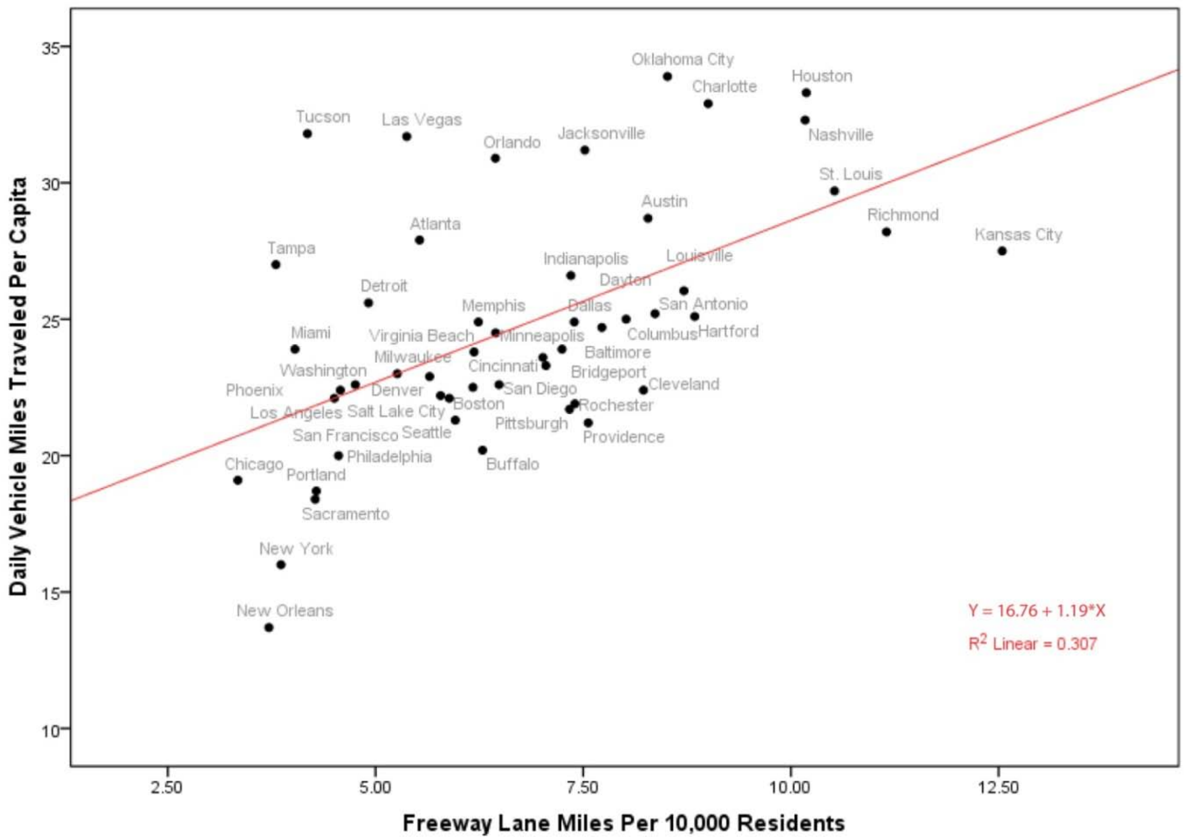


Figure 3: Vehicle Miles traveled by Freeway Lane Miles per Capita, top 50 US Metropolitan Areas (Source: US Department of Transportation 2008)

Accessibility and Sustainability

The power of the accessibility concept does not stem only from its capacity to rise above seemingly intractable debates over the relationship between the built environment and travel. Rather, the notion of accessibility—much more than the unidimensional idea of VMT reduction—is inherently bound up with the concept of sustainability. This is because accessibility can simultaneously serve the three dimensions of sustainability: environment, equity and economy. Reductions in auto trips mitigate the environmental impact of the automobile, and this study of metropolitan accessibility is in large part oriented towards planning for environmental gain. Yet auto-use reductions in isolation fail to serve the tripartite goals of sustainability.

By contrast, accessibility focuses not on the austere value of travel reductions alone, but on the capacity of the built environment to offer a high quality of life while offering a range of options for travel—not just long distance auto trips. Because accessibility is always distributed differently between socioeconomic groups and geographic regions, it lends itself to equity-based analyses, and these are central to this study. One can, for example compare the accessibility of low-income, carless residents of central cities between multiple metropolitan areas (Kawabata 2003), the relative accessibility of drivers and transit users between regions (Kawabata and Shen 2006) or the equity of the distribution of accessibility from one region to the next. The evaluation of accessibility also inherently incorporates dimensions of the urban economy, which thrives on interaction among locations within a metropolitan region. The capacity of accessibility to capture dimensions of environment, economy, and equity simultaneously makes it the crucial link between transportation and the built environment on the one hand, and sustainability policy on the other.

In the specific dimension of environment, if high-VMT regions are also turn out to be high-accessibility regions, one might conclude promotion of accessibility is at odds with sustainability planning. By contrast, if higher-density, low-VMT regions simultaneously enjoy higher levels of accessibility, it may be that planning for accessibility is consistent—perhaps even synonymous--with planning for transportation sustainability. "Sustainable development" was famously defined by the Brundtland (1983) Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The definition is abstract, and by itself gives little guidance to decisionmakers on applied planning questions. In broadest terms, however, one can conceive of three possible directions of increasing the sustainability of any situation:

1. *Reducing needs*. For example, if the good in question is electricity, one sustainability-promoting policy would be simple reduction in the consumption of electrical energy.

2. *Reducing the impacts of need fulfillment*, whether through mitigation or innovation. Thus the impact of electricity generation can be mitigated through better control technology, or reduced through innovative means of production.
3. *Redefining needs*. As a practical matter, the need is not for electricity per se, but for the services that electricity provides, such as illumination or computing power. Gauging the quality of these services through the wattage of computers or light bulbs would be a serious error; these are more properly assessed with metrics like luminous flux or million instructions per second, respectively. Assessing the success of transportation through metrics of mobility—an intermediate good whose demand is derived from people's need to reach their destinations—is a similar analytic error.

This redefinition of transportation needs in accessibility terms (Hansen 1959, Handy and Niemeier 1997) offers an alternative basis for sustainability policy regarding the built environment (Kwok and Yeh 2004). Where travel-behavior studies are subject to methodological uncertainty regarding the direction of causation, the determinants of accessibility are clear: an area is more accessible when a person can reach more destinations from it with a given time and money budget. Thus when one compares the change in accessibility of an area over time—or the accessibility of one area compared to another—the determinants can be definitively decomposed into the nature and number of the destinations reachable from that area and the characteristics of the transportation network connecting the area with others (Grengs 2004).

Motivating Question

There is a view prevalent in the urban planning and transportation literature that a low-density, auto-oriented metropolitan form is also a low-accessibility form (Ewing, 1994). That is, while an auto-oriented form may support rapid travel, it is thought to demand large investments of time and money in transportation in order to offer its residents access to their ordinary daily needs. The implications of this view would be far-reaching. A mobility-based transportation-planning logic frequently militates towards development of low-density areas that support rapid highway travel. If these forms of development turn out to degrade metropolitan accessibility overall, there would be a transportation basis for compact-city planning. The problem is that the assertion that low-density, auto-oriented development is a low-accessibility form has little basis in empirical analysis. It is certainly not true by definition; it may well be that more rapid travel in low-density metropolitan regions more than compensates for the great distances between their origins and destinations. Are low-density, auto-oriented metropolitan regions actually low-accessibility regions, as frequently claimed in the literature?

Study Approach

The research project initially proposed to analyze at least 30 out of the 50 largest metropolitan regions in the United States for their accessibility characteristics. To meet this goal, the metropolitan planning organizations (MPOs) of the 50 largest metropolitan regions (ranked on the MSA population count of Year 2000) were contacted with a request for travel-demand modeling data, the central piece of data needed for calculating accessibility scores in this project.

Selection of metropolitan regions

Due to the variation in the practice of travel demand modeling by different metropolitan regions, sufficient data from 38 metropolitan regions were received; the remaining 12 metropolitan regions were left out of the study. Table 1 shows the 38 metropolitan regions included in the analysis.

Table 1: Metropolitan Regions Included in the Study**Metropolitan Region**	**Size Rank**	**2009 MSA Population**
New York	1	19,069,796
Los Angeles	2	12,874,797
Chicago	3	9,580,567
Dallas	4	6,447,615
Philadelphia	5	5,968,252
Houston	6	5,867,489
Washington, D.C.	8	5,476,241
Atlanta	9	5,475,213
Boston	10	4,588,680
Detroit	11	4,403,437
Phoenix	12	4,364,094

San Francisco	13	4,317,853
Seattle	15	3,407,848
Minneapolis	16	3,269,814
San Diego	17	3,053,793
Baltimore	20	2,690,886
Denver	21	2,552,195
Portland	23	2,241,841
Cincinnati	24	2,171,896
Cleveland	26	2,091,286
Orlando	27	2,082,421
San Antonio	28	2,072,128
Kansas City	29	2,067,585
Las Vegas	30	1,902,834
Columbus	32	1,801,848
Charlotte	33	1,745,524
Indianapolis	34	1,743,658
Virginia Beach	36	1,674,498
Nashville	38	1,582,264
Memphis	41	1,304,926
Louisville	42	1,258,577
Richmond	43	1,238,187
Oklahoma City	44	1,227,278
Hartford	45	1,195,998
New Orleans	46	1,189,981
Buffalo	50	1,123,804
Rochester	51	1,035,566
Tucson	52	1,020,200

For these 38 metropolitan regions, the study sought to calculate four accessibility measures: 1) accessibility to work destinations via automobile; 2) accessibility to work destinations via transit; 3) accessibility to nonwork destinations via automobile; and 4) accessibility to nonwork destinations via transit. Due to the unavailability of certain data items, a subset of these measures was calculated for some metropolitan regions.

The availability of each of the four accessibility measures for each of the 38 metropolitan regions is shown in Table 2 below.

Table 2: Availability of Four Accessibility Measures of 38 Metropolitan Regions in the Study

Metropolitan Planning Organization Region	Accessibility to Work Destinations via Automobile	Accessibility to Work Destinations via Transit	Accessibility to Non-Work Destinations via Automobile	Accessibility to Non-Work Destinations via Transit
Atlanta	Y	Y	Y	Y
Baltimore	Y	Y	Y	N
Boston	Y	Y	N	N
Buffalo	Y	N	Y	N
Charlotte	Y	Y	Y	Y
Chicago	Y	Y	Y	N
Cincinnati	Y	Y	Y	Y
Cleveland	Y	Y	Y	Y
Columbus	Y	Y	Y	Y
Dallas	Y	Y	Y	Y
Denver	Y	Y	Y	Y
Detroit	Y	Y	Y	Y
Hartford	Y	N	Y	N
Houston	Y	Y	Y	N
Indianapolis	Y	N	Y	N
Kansas City	Y	Y	Y	Y
Las Vegas	Y	Y	Y	N
Los Angeles	Y	Y	Y	Y
Louisville	Y	N	Y	N
Memphis	Y	Y	Y	Y
Minneapolis-St. Paul	Y	Y	Y	Y
Nashville	Y	N	Y	N
New Orleans	Y	N	Y	N
New York	Y	Y	Y	Y
Oklahoma City	Y	N	Y	N
Orlando	Y	N	Y	N
Philadelphia	Y	Y	Y	Y
Phoenix	Y	Y	Y	Y
Portland	Y	Y	Y	Y
Richmond	Y	Y	Y	Y
Rochester	Y	N	N	N
San Antonio	Y	N	Y	N
San Diego	Y	N	Y	N
San Francisco	Y	Y	Y	Y
Seattle	Y	Y	Y	Y
Tucson	Y	Y	Y	Y
Washington, D.C.	Y	Y	Y	Y
Virginia Beach	Y	Y	Y	Y
Count of "Y"	**38**	**27**	**36**	**22**

Note: "Y" = available; "N"=unavailable.

Data sources and methods

The unit of analysis of this study is a metropolitan area defined by the local MPO. The study's primary unit of observation is a Travel Analysis Zone (TAZ). Data needed for the project divide into four groups: travel demand modeling data, business establishment data, spatial data, and population and socio-economic data.

First, the most important data item is travel demand modeling data, which are used for the calculation of the four accessibility measures, as mentioned in the previous section. These data contain matrices of interactions between all zones in the region, including travel times and travel flows (i.e., number of trips) between zones. The zonal interactions are provided in several levels of detail, by travel mode (auto and transit), by time period (during congested peak period conditions and less congested off-peak conditions), and by trip purpose (home-based work and home-based nonwork trips). The "auto" travel mode is defined as travelling in single-occupancy vehicles. The "transit" travel mode includes all possible public transit modes available in the metropolitan region, which may include such modes as bus, express bus, commuter bus, rail, commuter rail, and subway. In the case where multiple transit modes are available between two zones, the shortest possible travel time among all modes as the zonal was defined as the travel time, and the combined trips by all transit modes was considered as the zonal travel flow. The definition of peak hours varies slightly from MPO to MPO. Each MPO's definition of morning peak period was accepted in order to reflect the commuting rush hours in the mornings for each metropolitan region, usually from 6 am to 9 am. The off-peak period is defined as midday hours or midnight hours, depending on what is used by the MPO.

Second, for work and non-work destinations, the project purchased data on business establishments from the private vendor Claritas, Inc. (Claritas 2002). The Claritas data are collected from a variety of sources, including the U.S. Department of Labor, telephone books, county agencies, the U.S. Postal Service, and private utility companies. This dataset from Claritas contains several attributes of business establishments, including the number of jobs at a location (in terms of geographic coordinates) in 2008, and classification codes from the North American Industry Classification System (NAICS) allowing identification of businesses by industry type. All business establishments within the 38 metropolitan regions were geocoded to the street-address level, then aggregated by TAZ into the number of work and non-work destinations. The definition of non-work destinations is explained below.

Third, the project collected spatial data files, including boundaries of MPOs and TAZs, which were obtained from the MPOs. In addition, block group boundaries and street networks were collected from the U.S. Bureau of the Census.

Fourth, for equity analysis purposes, the project relied on population, race, income, poverty and employment status data at various geographic levels as outlined in Table 3 below.

The project required processing data from different sources into consistent formats and cross-checking the data with other sources to ensure validity. Before calculating accessibility indicators, a data consistency analysis was implemented to assure that attribute compositions were consistent among all MPOs, and spatial and attribute data were consistent for each MPO.

In addition to the data consistency analysis, the spatial variation of travel time and travel distance data was validated using both spatial and statistical analysis. First, by aggregating the travel-demand model data at TAZ origins, \ an average travel time at each TAZ in a region was calculated. Second, patterns in maps were inspected visually. Normally, the average travel time should be shortest in the center of a metropolitan region and longest in the periphery. Third, in regions where unexpected patterns were discovered, 50 zonal pairs were randomly selected and their travel times obtained from the MPO were cross-checked with travel times computed by Google Maps. If the travel times computed by Google Maps deviated significantly from the model travel times, a possible data error from the modeling dataset was confirmed. Under such a circumstance, we contacted the MPO again, explained the issues, and asked for a new dataset. This process may be repeated until the dataset we received passed all the validity tests,

Gravity-Based Accessibility

This study bases it accessibility metrics in the gravity model (Isard 1960,Wilson 1971), a powerful conceptual tool because it simultaneously accounts for both the transportation network and its surrounding land-use conditions (Handy and Niemeier 1997). Measures of accessibility derived from a gravity model are commonly used by urban planning scholars to evaluate the relative ease of reaching jobs in a metropolitan region (Cervero, Rood, and Appleyard 1999). This study uses a common form of the gravity model, proposed by Hansen (1959), and modified to account for two types of trip purposes (work and nonwork destinations) and for two travel modes (auto and transit):

$$(A_i) = \sum_j O_j F(c_{ij}) \qquad (1)$$

where:

(A_i) is the accessibility index for people living in zone i.

O_j is the number of opportunities in destination zone j; for work travel the value is the sum of jobs in a zone, for nonwork travel the value is the sum of nonwork attractiveness (described below) in a zone.

$F(c_{ij})$ is a composite impedance function capturing travel conditions across multiple metropolitan areas, associated with the cost of travel c for travel between zones i and j.

The $F(c_{ij})$ bears some explanation. The term is equal to $\exp(-\beta\ T_{ij})$, where exp is the base of the natural logarithm, T_{ij} is the travel time (minutes) between zones *i* and *j*. β is a parameter empirically derived to maximize the fit between predictions of the gravity model and observed distributions of travel times.

Accessibility measures can be calculated for either individual persons or for places. Individual-based measures seek to account for the variety of preferences or constraints that travelers have (Ben-Akiva & Lerman, 1979; Hägerstrand, 1970). For example, living in a zone with high accessibility to a medical clinic provides much utility to a person whose medical plan affords access to that facility, but little utility to someone who does not. The utility of the proximity would also vary with the individual's health and knowledge of medical services available to him. Thus one can conceive a range of accessibility metrics, from the most partial to the most comprehensive, developed for different purposes. This study uses the gravity model as a "place-based" measure, for two main reasons. First, although it is possible to construct individual-based measures, they require collecting an extraordinary amount of data on personal preferences. Such a data collection effort would not be possible in an intermetropolitan comparison study like the current one.

The second reason this study prefers a place-based measure is that it better matches the core policy tasks of urban planners: designing and implementing land-use and transportation policy at the level of places. This study's approach is to assign the same level of accessibility to every person residing in a zone, regardless of their personal preferences for travel. The gravity model produces a measure of the *potential* for people living in a spatial zone to reach destinations. It does not address whether people actually choose to use the potential. The land-use or transportation planner seeking to increase accessibility to medical clinics cannot know the medical coverage of future residents of a zone, but can forecast place-based variables like density and travel speeds. Thus an accessibility measure designed for land-use and transportation planners is most useful when it is place-based.

A disadvantage of the gravity model is that the results by themselves are not easily interpreted. As an alternative, "cumulative opportunities" measures were computed because they offer the advantage of a more direct interpretation (for example, 100 jobs within 10 minutes). The problem, however, is that the direct interpretation comes at too steep a price: whichever threshold distance is selected (for example, 30 minutes travel) rigidly cuts off from consideration all that lies beyond it, undermining the goal of considering all destinations in a region. Furthermore, cumulative opportunities measures have the additional weakness of weighting equally all destinations within the travel threshold, even though distant destinations are actually less desirable than those nearby. A gravity model overcomes these weaknesses by weighting destinations differently according to travel time, and by including all destinations within the study area.

Work and Non-Work Accessibility

Four accessibility measures were calculated where possible: work-auto, work-transit, non-work auto, and non-work transit. Each TAZ in every metropolitan region receives one accessibility score for each of the four measures if data are available, and all residents living in the same TAZ are considered to be assigned the same accessibility scores as of the TAZ. The only exception is in the equity analysis portion, where accessibility scores of the TAZs are matched with household vehicle availability.

For employment accessibility, work destinations account for all employment in the metropolitan region, regardless of industry type or occupation category. Every job in a destination TAZ is considered as one work destination for the residents in the origin TAZ. This approach consciously overlooks the fact that there are skill mismatches between jobs and workers: not every job is appropriate for every worker, and vice versa—a simplification taken because of the transportation and land-use context for which these metrics are developed (as described above).

The definition of nonwork destinations was somewhat more intricate. The project sought to develop a general metric of the attractive capacity of non-work destinations, rather than sector-by-sector metrics. Work and work-related trips account for only 17.7 percent of all trips nationwide (National Household Travel Survey 2001), so a definition of nonwork destinations is at least as important as work travel for the study of accessibility. For travel to work, the attractiveness of a zone is straightforward: the number of jobs in each destination zone was used as a measure of the number of opportunities. For travel involving nonwork purposes, the attractiveness of a zone is more complicated because of the wide range of destinations available. Common nonwork trip purposes include shopping, errands, and purchasing goods (28.8% of nonwork trips); meals and other social events (12.9%); visiting friends and relatives (11.3%); exercise or sports (7.1%); and purchasing services (6.9%) (National Household Travel Survey 2001).

The problem of defining nonwork destinations has been approached in a number of ways in previous studies. Ettema and Timmermans (2005) used people's duration of nonwork activities as an indicator of the attractiveness of nonwork destination: the longer a person spent time at a destination, the more valuable it was considered to be. Apparicio and Seguin (2005) defined six types of destinations (cultural services, educational services, health services and facilities, sport and recreational facilities, bank branches and other types of services and facilities) and used cluster and factor analyses to combine these into an accessibility metric. Martin and Reggiani (2007) estimated intercity accessibility via high-speed rail, and used the gross domestic product of each urban agglomeration as their indicator of destination attractiveness. Kwan and Weber

(2008) implemented Hägerstrand's (1970) time-space accessibility using locations of actual activity participation from a household travel survey.

The approach used here (Appendix F) started with the trip purposes in the National Household Travel Survey (NHTS). The NHTS classifies trip purposes into 35 categories and reports the proportion of trips nationwide that are made for each of these purposes. The measure used here is designed to implement a nonwork attractiveness index for each metropolitan region weighted according to the trip frequency of NHTS trip purposes; thus if retail accounts for X percent of nonwork trips, it should similarly account for X percent of the nonwork attractiveness index. The distribution of nonwork trips in a given metropolitan area was assumed to match the nationwide distribution of trips in the NHTS. This assumption is a limitation of the method, but the alternative of relying on household travel surveys from multiple Metropolitan Planning Organizations (MPOs) proved impractical. Subsets of jobs were then classified as relevant to nonwork travel. For example, while jobs in industrial plants would not serve as nonwork destinations, jobs in facilities including grocery stores, restaurants, or churches would.

This method required the development of a correspondence between NHTS destinations and North American Industry Classification System (NAICS) codes, the system used to characterize jobs by industrial sector. Certain modifications needed to be made to develop this correspondence. For example, some classifications in NHTS such as "transport someone," "pick up someone," "take and wait," or "drop someone off" are reasonably clear as trip purposes but cannot readily be linked to specific destinations and were hence dropped from the analysis. Other trip-purpose classifications, such as "buy goods: groceries/clothing/hardware store," "medical/dental services," or "get/eat meal" were easily assigned relevant NAICS codes. Some trip purposes (e.g., "go to religious activity" and "attend funeral/wedding") were merged because while the trip purposes were distinct, there was significant overlap in the destinations. Finally one trip purpose, "visit friends/relatives" had no potential indicator among the employment-based NAICS codes; population, rather than jobs, was used as the indicator for this trip purpose.

In some cases, business types were excluded from the analysis for lack of relevance to accessibility from one's home zone. For example, hotels and other tourist destinations were excluded since these are usually most relevant when not making trips from home. Car dealerships, which account for a significant number of jobs, were excluded since the low frequency with which people visit these establishments renders them only marginally relevant to home-based accessibility. By contrast, hospitals were included despite their low frequency of visits since these were assumed to have a significant option value: their presence provides an assurance that augments one's accessibility even when they are infrequently used. After dropping and merging categories, a set of 24 nonwork trip categories were selected to be linked to NAICS codes.

A problem with using employment as the indicator for attractiveness is that jobs have different capacity to attract trips: for example, a job in a grocery store through which hundreds of people pass daily would effectively attract more trips than a job in an accountant's office. With a set of destinations defined, and the number of jobs or population at those destinations identified, the potential attractiveness of a job or person in each category was assessed based on the "trip draws" of each category (a detailed explanation and formulas can be found in the endnotes). Finally, using the "nonwork attraction index," nonwork accessibility indicators were calculated following the standard gravity model formulation.

Auto and Transit Accessibility

Another dimension of complexity involved in the accessibility measure calculations presented here is the two types of travel modes: automobile and transit. Travel times by automobile are reasonably comparable across metropolitan regions as provided by MPOs. Travel times by public transit, however, are more complicated and are not necessarily comparable across metropolitan regions without verification. To verify that transit travel times were comparable across the metropolitan cases required several steps.

The first step was to ensure a common set of components in the transit travel times. Transit travel times consist of several components, including access time, egress time, waiting time, transfer time, and in-vehicle time. The transfer time and in-vehicle time are components that are reasonably consistent among metropolitan regions, and these data were used as provided by the

MPOs. The components of access time and egress time, by contrast, are not consistent among regions; these were calculated using a three-mile-per-hour walking speed. Waiting time is the most complicated component of total transit travel time. The common approach among MPOs to calculating waiting times in travel demand models is to use a function that converts the various headways – the amount of time between buses or trains on the same line – into an average waiting time. These functions, provided by some MPOs, were used to verify that the conversion from headways to waiting times was reasonably consistent across regions.

A second step was to ensure consistency in the way that multiple transit modes were handled. As described above, in the cases where an MPO provided transit travel times by multiple modes, the shortest total travel time among the various modes were used, on the assumption that a traveler typically would select the fastest option available.

A third step was to consistently assign travel times among zones that are not served by public transit. By assuming that a person without a private vehicle has no alternative but to walk, transit travel time was estimated based on a constant walking speed of three miles per hour.

Finally, the consistency of total transit travel times across metropolitan regions was tested by comparing a sample of zone-to-zone times from each metropolitan region against a different data source. A random sample of at least 30 zonal pairs in each region was compared against the predicted travel time by transit produced in Google Maps. The transit travel times obtained from MPOs differed from those in Google maps by no more than 10 percent on average for most regions. Regions with sparser transit availability deviated somewhat more from the Google Maps estimate, in part because Google maps offered data from relatively fewer zonal pairs for these regions.

Population Distributions of Accessibility

Though the methods described above are place-based—i.e., they assign identical accessibility scores to everyone living in a particular zone—the project was interested in the accessibility of people, not the zones in which they live. A high-accessibility residential zone would contribute little to the accessibility of the metropolitan population if municipal land-use policy severely restricted the number of households that could live there. For this reason, and to facilitate intermetropolitan comparison, accessibility levels are reported here in terms of the percentage of population that experience them.

High accessibility zones have little value if people do not actually experience them. The three-dimensional map of Figure 4 provides an illustration of this idea for the case of San Francisco. In the figure, the distribution of accessibility across space is shown by the shading, with the darkest shades indicating the highest levels of accessibility. Population density is shown in the map as a height to depict where people live relative to accessibility. Figure 4 suggests that a large proportion of the regional population lives in high accessibility zones.

Three-dimensional maps allow for visual comparisons of metropolitan regions. Comparing Figure 4 to Figure 5 reveals that people in San Francisco tend to live in higher accessibility zones than their counterparts in Washington, DC. For example, population density is high in much of the territory around the rim of the bay in San Francisco, where accessibility is highest. By contrast, population densities are less substantial in the territory of highest accessibility in Washington, DC. In other words, though a high-accessibility zone forms around central Washington, D.C., the relatively low population of that zone (as compared to San Francisco) limits its contribution to overall accessibility in the D.C. region.

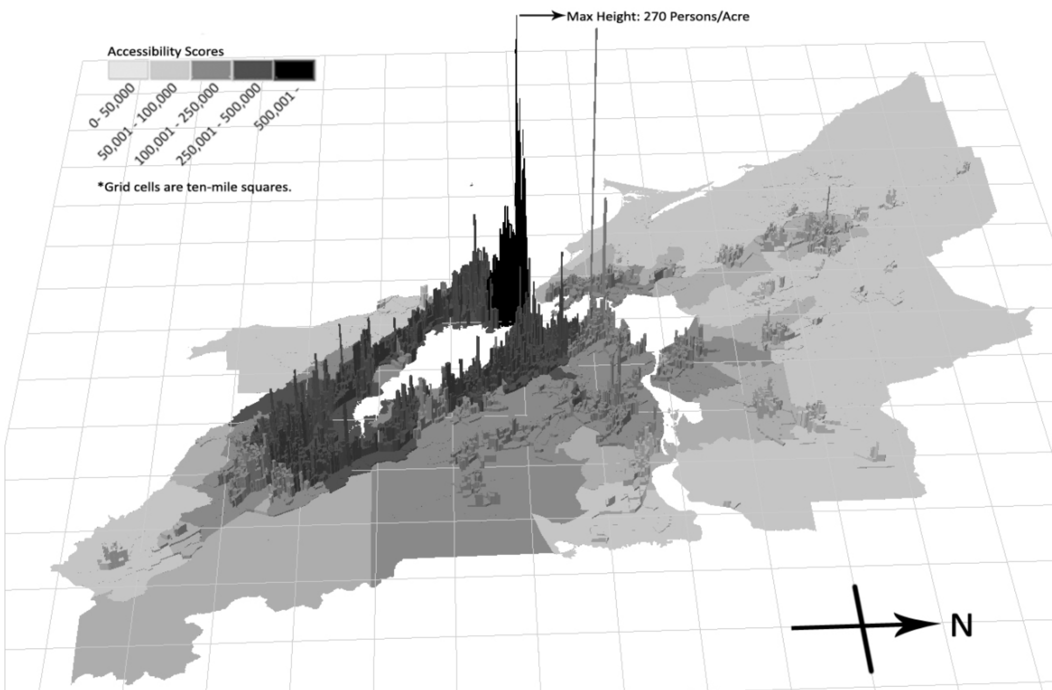


Figure 4. Accessibility to Work by Auto, with Population Density, San Francisco, 2000

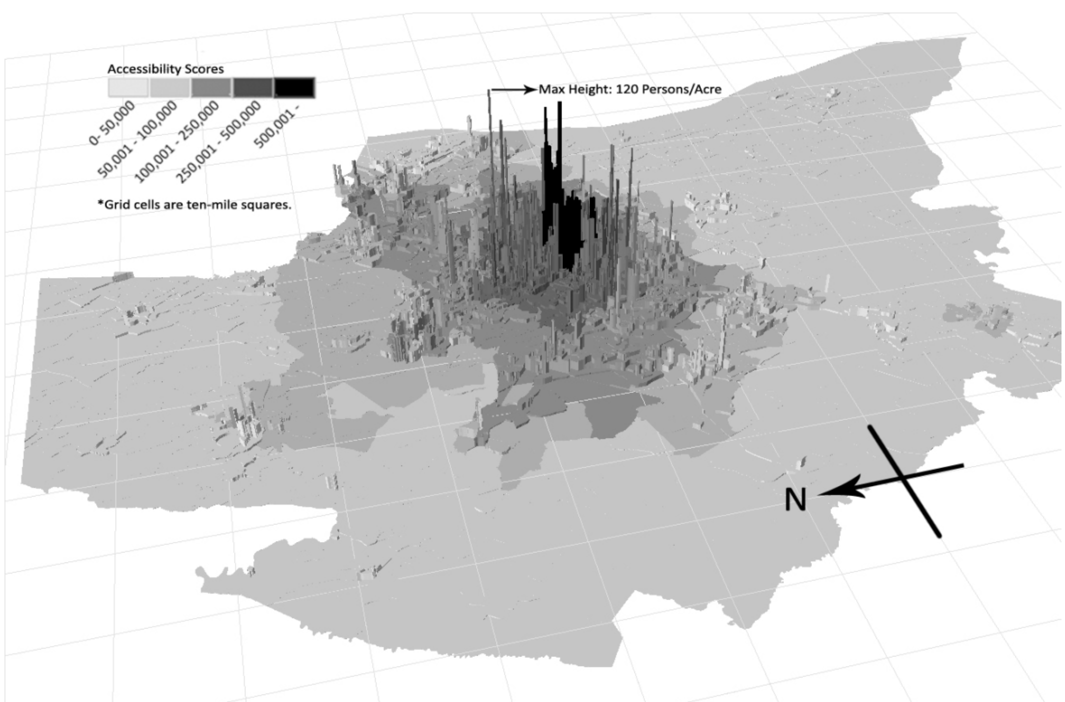


Figure 5. Accessibility to Work by Auto, with Population Density, Washington, DC, 2002

To quantify these visual observations, accessibility indices are plotted against the regional share of population, as shown in Figure 6. The chart in panel A shows that San Francisco residents experience higher accessibility to jobs by auto than residents in Washington, DC across the entire regional population. To illustrate, the median resident in accessibility terms (found at the 50th percentile mark) experiences job accessibility at a value of 270,000 in San Francisco, but only 143,000 in Washington, DC. Alternatively, comparing the accessibility index value of 200,000 across the regions reveal that 66 percent of the population in the San Francisco region experiences at least this level of accessibility, compared to only 36 percent of the population in Washington, DC.

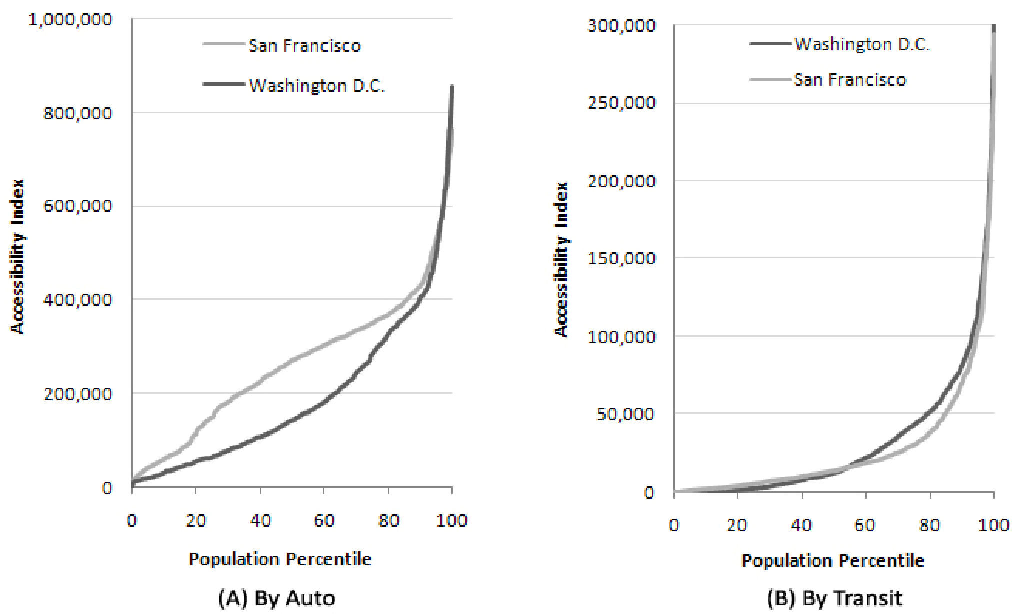


Figure 6. Accessibility to Work by Population Percentile, San Francisco (2000) and Washington, DC (2002), for (A) Automobile Travel and (B) Transit Travel

Pooled Impedance

For the purposes of intermetropolitan comparison, numeric results generated by a gravity model must be comparable on a common scalar across metropolitan regions. The first two parameters in the model—the attractiveness factor and travel time—are readily comparable, because the meaning of the concepts "job" and "minute" are reasonably constant across different metropolitan regions. But the third parameter—the distance-decay coefficient—raises a challenging methodological puzzle because it is a reflection of behavior, and travelers behave differently depending on which metropolitan region they live in. The physical size of a region, the diversity of opportunities, and the geographic distribution of opportunities reflected in land use patterns will all influence the willingness of a resident to travel long distances. A traveler in Los Angeles, for example, is more likely to make a long trip of sixty minutes than a traveler in a smaller region like Omaha, partly because Los Angeles is so much larger than Omaha and partly because more opportunities exist an hour away from residents in Los Angeles, making a long trip more worthwhile than for residents in Omaha.

The distance-decay coefficient is normally estimated for a single metropolitan region, by calibrating a gravity model with detailed data on trip making patterns from a household travel survey (Transportation Research Board 1998). The coefficient is empirically derived as a best-fit solution to observed behavior among a sample of travelers in a single metropolitan region, an approach that is commonly used in studies of accessibility (Appendix D; Isard 1960, Wilson 1971, Handy and Niemeier 1997). This approach implicitly treats all travelers in a region as if they experience the same distance-decay function, even though in reality travelers within a region exhibit a great deal of variation in their willingness to travel long distances. The implicit assumption is that the distance-decay coefficient is an expression of the normal behavior of the average traveler in a region. Thus, all distance-decay functions in use are in fact composite distance-decay functions.

The multi-region nature of the current study required a pooled factor representing all regions. This intermetropolitan comparison could not take the typical approach of deriving a distance-decay coefficient separately for each metropolitan region because this would render accessibility indices incomparable across the cases. Imagine, for example, the contrast between a compact and sprawling metropolitan region. People in the sprawling region will be observed to travel long distances both because there are relatively few destinations nearby and because there are many at great distances. The distance-decay coefficient for this region will be relatively low, ostensibly indicating a great willingness of individuals to travel. Yet this willingness is in large measure a function of necessity: they need to travel long distances to meet their needs. By contrast, in the compact region, trips are relatively short, and the region-specific distance-decay function would seem to indicate a relative unwillingness to take longer trips. Using region-specific distance-decay functions in intermetropolitan comparisons of accessibility is tantamount to giving the sprawling region accessibility "credit" for its long travel distances: since people need to travel farther there, they are revealed to be willing to travel farther there and, as a consequence, are able to reach more destinations. Breaking the circularity of this logic and generating meaningful intermetropolitan accessibility comparisons demands a pooled distance-decay factor. While the region-specific distance-decay factor is a longstanding fixture in transportation modeling practice—and its aggregation from the individual level is an accepted simplification—it is inadequate to the task of intermetropolitan accessibility comparison.

To make a meaningful comparison across multiple metropolitan regions, therefore, this study's approach is to estimate the typical behavior of median traveler in all the regions combined.
The study faced a similar decision when choosing an approach to comparing auto and transit accessibility. Transit users generally spend more time in travel than their auto-driving counterparts, primarily because their travel networks require more time to accomplish the same number of activities. As a consequence, the value of their impedance function would be lower than that of drivers. Interpreting that greater time spent as greater *willingness* to spend time in travel would lead the analyst to underestimate the accessibility gap between cars and transit; since transit users are "willing" to travel longer times, their capacity to reach destinations will be closer to that of car drivers than it would otherwise be. But if this ostensible willingness is primarily a function of transit's slower travel, then the analysis will, in a circular fashion, credit transit for its longer travel times. For this reason, the study uses a single (auto-based) impedance function for both modes, just as it uses a single impedance function to compare the regions. While this approach deviates from imputing factors directly from observed behavior, it avoids the circular logic of crediting transit for its longer travel times.

Two possible methods can be used to develop the pooled impedance factor. The first method uses multiple regression to solve for the distance-decay coefficient in a gravity model (Fotheringham and O'Kelly 1989; Isard 1960; Sheppard 1984). This method was ultimately rejected because the results depend too heavily on the way that data are collected by each metropolitan region. A region's zonal system is constructed by the local MPO, and each system is highly inconsistent with another. The average zone size varies substantially, a factor that affects the total number of zones in any region. And the total number of zones in a region heavily influences the outcome of ordinary least squares regression, because the number of observations in a regression equation is the square of the number of zones in a region. Regions with unusually small average zone sizes result in a very high share of observations in a regression equation that combines metropolitan regions, essentially swamping the results over regions with larger average zone sizes. In principle, one could design a weighting system to reduce the influence of TAZ-rich regions on final estimation, but the study settled on a more direct method.

The study used an alternative method for arriving at a pooled impedance factor. Only 16 MPOs provided all the data required to estimate the β parameter. [2] The β parameters for these 16 metropolitan regions were negatively correlated with metropolitan population, a regression model was used to estimate β parameters; individual values of β were the dependent variable and metropolitan population was the independent variable. For work travel, the best-fitting regression is: estimated $\beta = 0.109*\exp(-3.52*10^{-8}*\text{Population})$. For nonwork travel, the best-fitting regression is: estimated $\beta = 0.24*\exp(-3.52*10^{-8}*\text{Population})$. These two equations were then used to predict the work and nonwork β values, respectively, for each of the 38 metropolitan regions. The β values (one for work, another for nonwork) for the 20th largest metropolitan region, roughly the median in population terms, were then used as the β values for the calculation of accessibility indicators in this research. [3]

It is important to note that the cumulative opportunities model does not solve the gravity model's problem of shared versus pooled impedance functions. This is because the choice of the travel time radius – e.g., 15, 30, or 45 minutes – is precisely analogous to the choice of a distance decay parameter, with a low parameter being parallel to a large search radius. The choice of both distance decay parameters in gravity-based accessibility and the search radius in the cumulative

[2] These 16 regions are: Los Angeles, Chicago, San Francisco, Philadelphia, Washington, D.C., Dallas, Detroit, Seattle, Phoenix, Minneapolis-St. Paul, San Diego, Portland, Cincinnati, Indiannapolis, Hartford, and Bridgeport-Stamford.

[3] The β value for work travel is: 0.10157; the β value for nonwork travel is: 0.2307.

opportunities model will influence both accessibility metrics, and potentially the ordinal ranking the accessibility of the metropolitan regions in the study.

The Method of Paired Comparisons and Decomposition of Accessibility Differences

In order to make comparisons across multiple MPOs with regard to accessibility levels, this study analyzed each region in comparison with a region of similar population size. Population was used as a criterion to establish comparison pairs because the four accessibility measures are highly sensitive to the total number of destinations within a metropolitan region. Regions with large populations tend to have many destinations as well; hence they tend to have high accessibility. Comparing accessibility scores between two similar-sized metropolitan regions facilitates the exclusion of the size effect to reveal the connection between certain urban forms and the accessibility measures.

Table 3. MPO Pairings and Their Populations

Pair	MPOs	MPO Population of Year 2000
1	New York	20,974,165
	Los Angeles	16,406,257
2	San Francisco	6,781,705
	Washington, D.C.	5,739,833
3	Philadelphia	5,383,397
	Houston	4,661,133
4	Dallas	4,883,746
	Detroit	4,809,619
5	Baltimore	4,928,768
	Boston	4,299,485
6	Seattle	3,257,550
	Atlanta	4,226,157
7	Phoenix	3,189,762
	San Diego	2,788,097
8	Cincinnati	2,692,422
	Minneapolis	2,620,705
9	Cleveland	2,147,400
	Denver	2,591,518
10	Portland	1,785,409
	Orlando	1,838,210
11	Kansas City	1,636,400

	Charlotte	1,683,438
12	San Antonio Indianapolis	1,616,126 1,606,810
13	Las Vegas Columbus	1,308,654 1,442,881
14	Memphis Richmond	1,059,382 948,140
15	New Orleans Louisville	1,082,061 968,218
16	Oklahoma City Hartford	990,369 970,483
17	Tucson Virginia Beach	830,402 1,514,981

For each pair of MPOs, the total difference between each of the four types of accessibility of the two MPOs is decomposed into two parts: the speed effect and the proximity effect. The speed effect is the difference in accessibility between the two MPOs that is due to the discrepancy in traveling speeds in the two regions. The proximity effect captures the remaining difference that could not be explained by traveling speeds. It reflects the impact of proximity on the accessibility of residents. Moreover, the speed effect and proximity effect derived by the decomposition methodology capture the difference in the magnitude as well as in the distribution of accessibility by population in two paired MPOs. Appendix E illustrates the mathematical derivation of the two effects in the decomposition of the difference in accessibility between two MPOs X and Y.

Urban Form and Metropolitan Accessibility

A central question of this study is the impact of urban form on accessibility outcomes, and in particular, what kind of metropolitan region provides a high level of accessibility to its residents. "Urban form" in this context can mean a host of characteristics, including centralization, concentration, density, and others. This study tested the impacts of a range of these attributes on accessibility outcomes (measured in this section as median work accessibility by auto). Metrics of centralization and concentration had little predictive power. By contrast, average metropolitan densities appeared to be a significant determinant of median work accessibility by automobile.

In part, this is a function of a focus on the median resident. The median resident (in accessibility terms) of any U.S. metropolis is a suburbanite. In all likelihood, this individual does not live in or near the downtown or even in or near a suburban concentration such as a downtown or transit-oriented development. Thus the extent of these concentrations affects this person only marginally. By contrast overall metropolitan densities can affect median accessibility markedly in two ways:

> -They can slow the traffic. Auto-ownership rates in U.S. metropolitan regions—including higher-density regions—is high. Thus population density in these regions can lead to high traffic densities and therefore slow speed. Holding distances constant, slower travel speeds would degrade accessibility.
>
> -They can shorten the distance between origins and destinations. Higher density regions put numerous destinations closer to a given origin than their lower-density counterparts. Holding travel speeds constant, shorter distances would increase accessibility.

Thus the effect of density on accessibility can be thought of as the net of the speed effect (represented as the left-hand side of Figure 7) and the proximity effect (represented as the right side). If the speed effect dominates, denser regions would be less accessible regions; if the proximity effect dominates, less accessible regions would be more accessible.

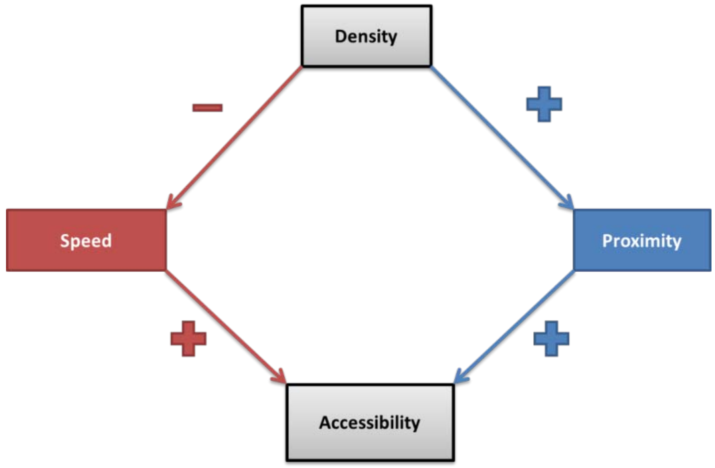
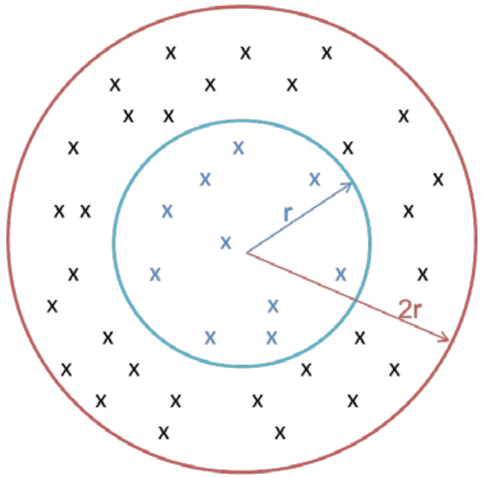


Figure 7: Routes of Influence from Density to Accessibility

There are theoretical reasons to argue both positions, as described below:

Possibility #1: The speed effect dominates the proximity effect.

One common measure of accessibility is a cumulative opportunities measure, or the number of destinations reachable within a given amount of time. This concept is used here to illustrate why the speed may dominate in producing accessibility. The territory accessible within Y minutes would be an irregularly shaped area (depending on the shape of the street network) but is simplified here as a circle and illustrated in Figure 8. Destinations are represented as Xs. When speed doubles, the radius of the circle that can be reached within a given time increases from r to 2r. As a consequence, the area of the circle quadruples from πr^2 to $4\pi r^2$. Given constant density of the destinations, the destinations reachable within the specified time also quadruple with the doubling of speeds. Thus in the case of the simple circle, accessibility increases with the square of speed.

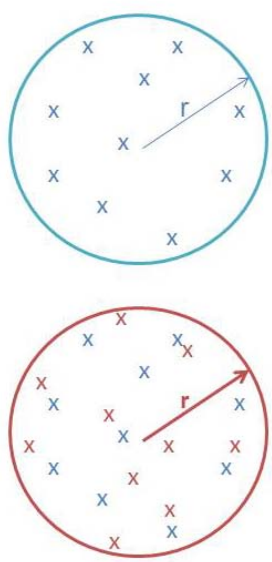


	Radius	Area	Density	Desti-nations or Accessi-bility
Smal-ler Circle	r	πr^2	$10/\pi r^2$	10
Lar-ger Circle	2r	$4\pi r^2$	$10/\pi r^2$	40

** Note: one x represents one destination*

Figure 8: Illustration of Speed Effect of Accessibility (holding destinations constant)

The impact of increasing densities on accessibility can be illustrated in a similar fashion. In Figure 9, speeds are held constant, but density of destinations is doubled, leading to a doubling of accessibility. Thus while accessibility increases with the square of speed, it increases linearly with density. Clearly, increasing speed confers a very significant accessibility advantage, one that will be difficult to overcome with the proximity effect.



	Radius	Area	Density	Destinations or Accessibility
Top Circle	r	πr^2	$10/\pi r^2$	10
Bot-tom Circle	r	πr^2	$20/\pi r^2$	20

Figure 9: Illustration of Density Effect of Accessibility (holding speeds constant)

Possibility #2: The proximity effect dominates the speed effect.

Notwithstanding the very evident benefit of speeds in producing accessibility, could the proximity effect dominate the speed effect? Figure 10 analyzes this possibility by decomposing the relationship between density and transportation speeds. On the one hand, low-density areas tend to have a high ratio of roadway lane-miles per capita (Figure 11), a factor that would tend to raise travel speeds in these areas.

Yet this factor tends to be at least partly negated by the higher VMT per capita observed in low-density metropolitan regions (Figure 2). These regions are thus simultaneously roadway-intensive and travel-intensive. Speeds are determined neither by VMT nor by roadway miles in isolation, but as a function of the interaction of the two. The relatively strong (R^2=0.26) negative relationship between density and VMT per capita interacts with a somewhat stronger (R^2=0.37) relationship between density and freeway lane miles per capita. The net result is that the relationship between population density and traffic density (Figure 12) is relatively weak (R^2=0.11). As a consequence, the relationship between density and travel speeds is a weak one: low-density regions display roadway speeds that are greater than those of higher-density regions, but this effect is quite slight, as will be shown below . Thus while the speed-accessibility link represented in Figure 9 is expected to be strong, the density-speed link may be quite weak.

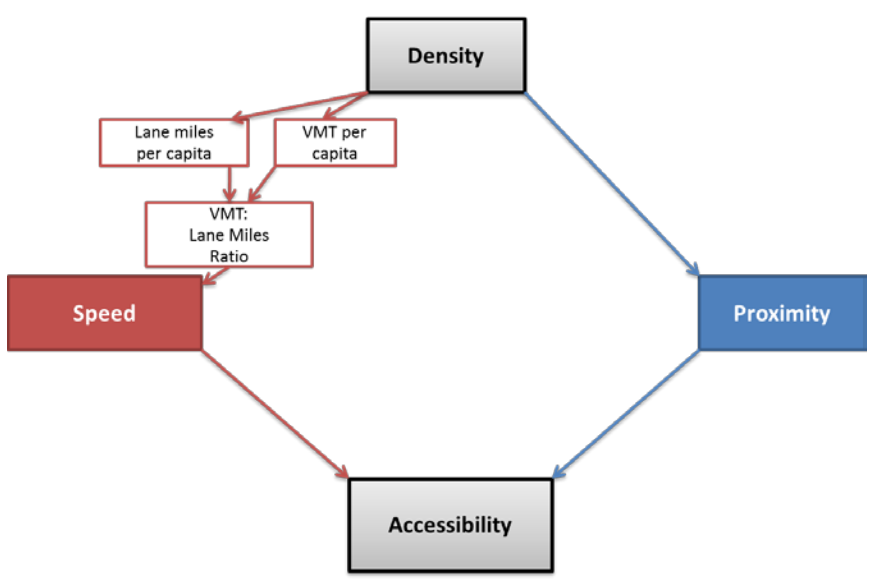


Figure 10: Decomposition of the Density-Speed Relationship

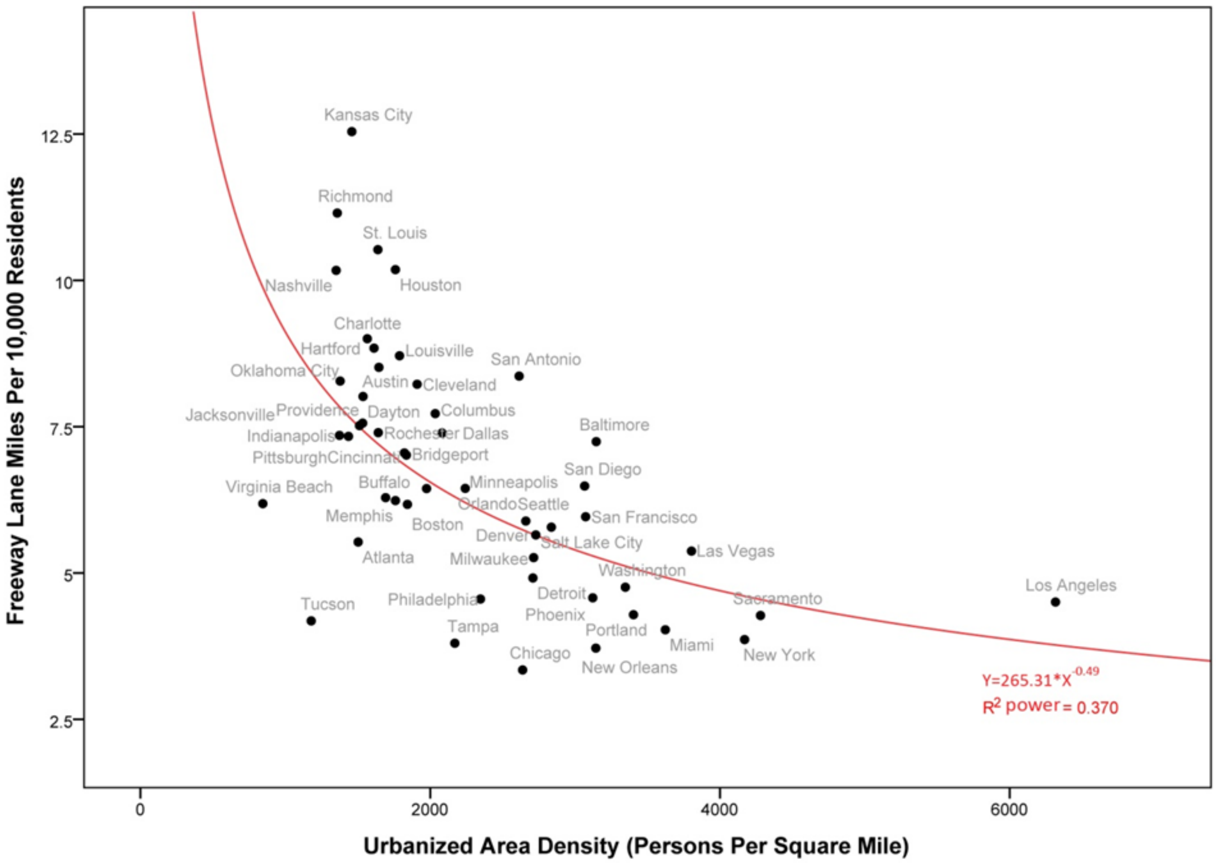


Figure 11: Urbanized Area Density and Freeway Lane Miles Per Capita

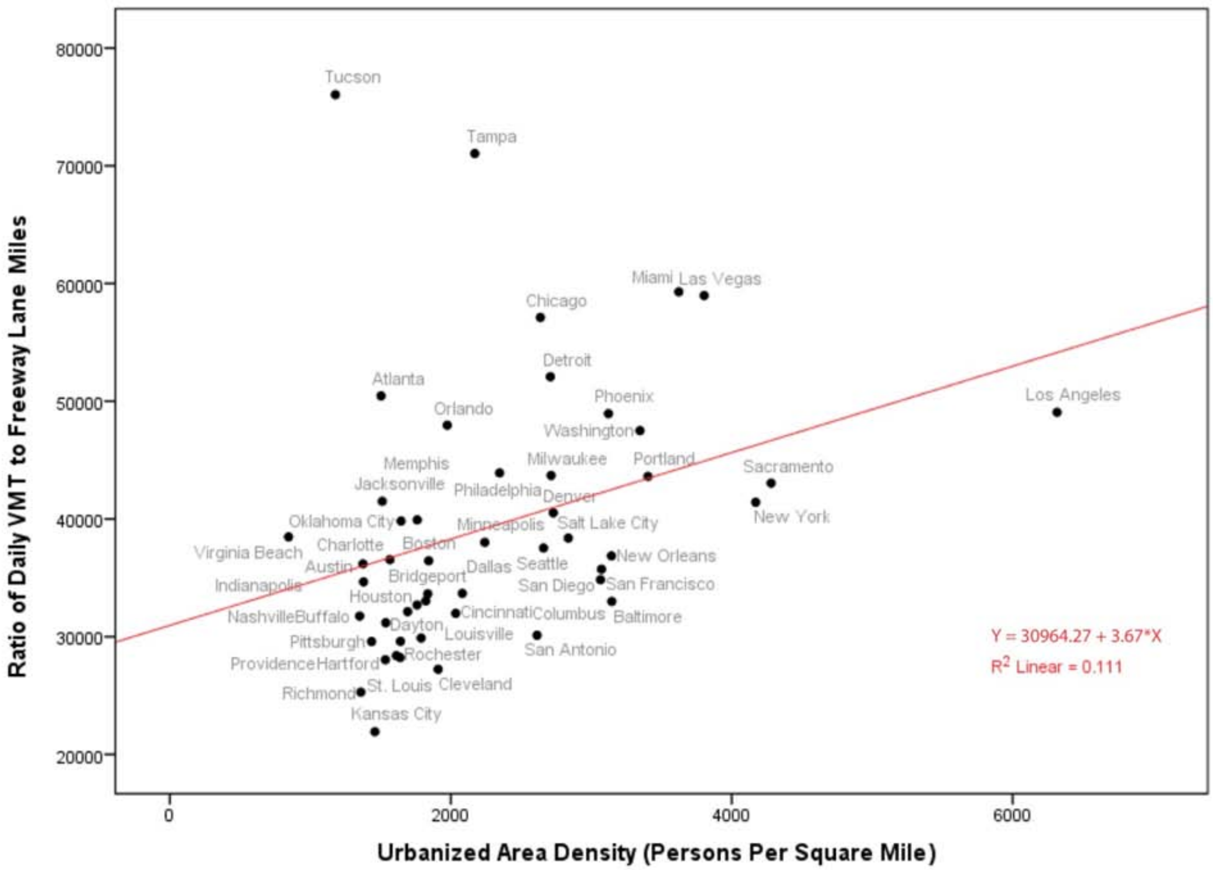


Figure 12: Traffic Density by Population Density

To test whether the data support Possibility #1 or Possibility #2, a path analysis was implemented with the metropolitan region as the unit of analysis, and using 38 metropolitan regions.. Results are depicted in Figure 13. Values represented along each link are standardized regression coefficients, a measure of the strength of the relationship between the variables shown in the diagram. The dependent variables of each regression are the variables to which the arrows point. Independent variables are those represented as pointing towards the dependent. For example, “weighted average auto speed” is the dependent variable in a regression with “highway speed limit” and “total daily VMT to total lane miles ratio” as independent variables.

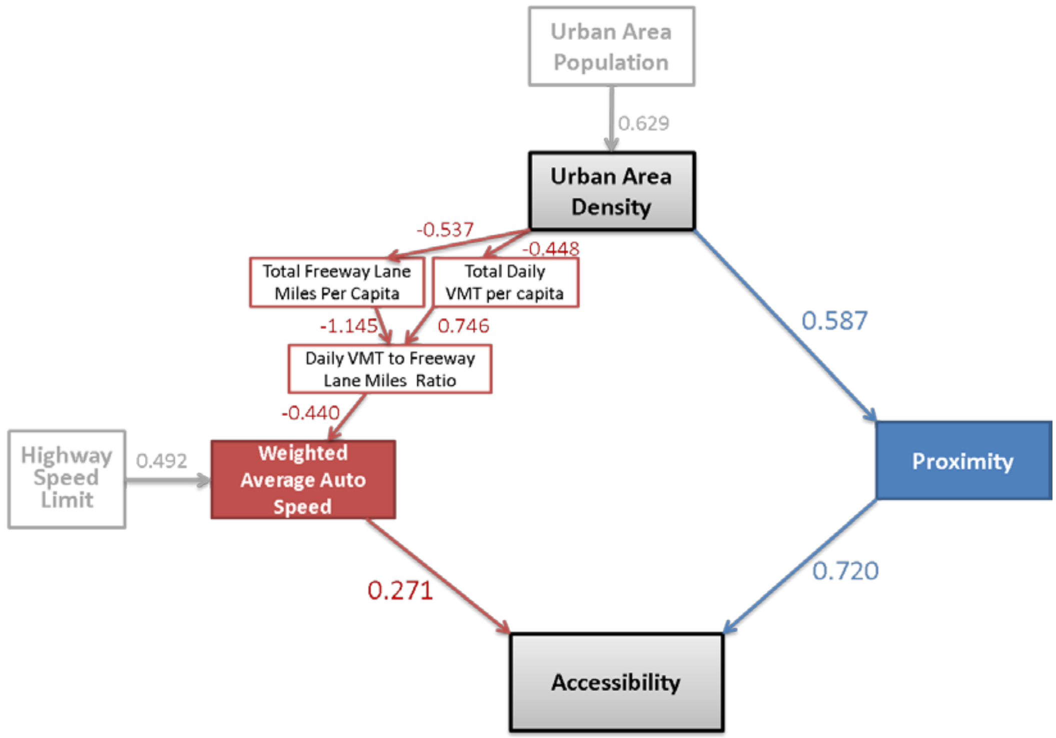


Figure 13: Path Analysis of Relationships of Density, Speed, Proximity, and Accessibility

Variables in Figure 13 are defined as follows:

Urban Area Density: Population of the urban area divided by its total land area in square kilometers (Source: Highway Statistics 2008, U.S. Federal Highway Administration).

Proximity: Median work accessibility when calculated as a gravity model using an impedance of straight-line distance between origins and destinations (to reflect the effect of pure distance unencumbered by a traveler's willingness to travel).

Accessibility: As described in the methods of this study, calculated as a gravity model using an impedance of peak-period travel time by automobile between origins and destinations. The variable is the median score for residents in the region.

Highway Speed Limit: The speed limit of the state or territory to which each metropolitan region belongs. Among the 38 MPOs in the current study, this variable takes one of the three values: 65 mph, 70 mph, or 75 mph.

Total Daily VMT Per Capita: Total daily vehicle miles traveled by the residents of the urban area divided by the total population of the urban area (Source: Highway Statistics 2008, U.S. Federal Highway Administration).

Total Freeway Lane Miles Per Capita: Total freeway lane miles within the urban area divided by the total population of the urban area, (Source: Highway Statistics 2008, U.S. Federal Highway Administration).

Total Daily VMT to Total Lane Miles Ratio: Total Daily VMT Per Capita divided by Total Freeway Lane Miles Per Capita.

Weighted Average Auto Speed: This variable is the average speed, weighted by the imputed travel volume for this zonal pair. This travel volume was imputed by multiplying the total population at the origin zone, the total number of jobs at the destination zone and an impedance function. The impedance function is an exponential function of the peak-hour travel time by automobile for this zonal pair and the pooled impedance factor for home-based work trips. In mathematical terms, the formula of calculating this weighted average auto speed is:

$$S = \frac{\sum_{i=1,j=1}^{i=n,j=n} \frac{D_{ij}}{T_{ij}} \cdot \frac{p_i}{P} \cdot \frac{w_i}{W} \cdot e^{-T_{ij} \cdot \beta}}{n^2}$$

Where, n is the number of TAZs in a metro; i is the origin TAZ; j is the destination TAZ; D_{ij} is the Euclidean distance between origin and destination; T_{ij} is the peak-hour travel time by automobile between origin and destination; p_i is the number of population in the origin TAZ; P is the total population in the metro; w_i is the number of work opportunities in the destination TAZ; W is the total number of work opportunities in the metro; e is the base of natural logarithms; β is the pooled impedance factor for home-based work trips, which is 0.10157.

In path analysis, weights along sequential paths are multiplied to calculate the weight (or strength of relationship) along the entire link; weights of parallel paths are summed. Thus the weight from density to speed may be calculated as: [(-0.537*-1.145)+(-0.448*0.746)]*(-0.440)=-0.123. As predicted, this link is weak relative to the other links shown in Figure 13, a function of its incorporation of two countervailing factors: low density regions are freeway-rich on a per-capita basis, but these regions simultaneously demonstrate high VMT per capita.

The effect of density on accessibility is thus the net effect of the positive effect via the greater proximity evident in denser areas and the negative effect of these areas' slower speeds. This net effect may be analyzed by comparing the composite weight along the left-hand path (via speed) and the right-hand path (via proximity). The weight along the entire speed path equals (-

0.123*0.271)=-0.033, while that along the proximity path equals (0.587*0.720)=0.423. Thus notwithstanding the advantages of speed in generating accessibility, density exerts a positive accessibility effect via proximity that is over ten times as strong as the negative effect via density.

These results—with the positive impacts of density on auto accessibility outweighing their negative impacts—are corroborated in Figure 14. Overall, the figure demonstrates a positive relationship between urbanized-area density and accessibility. There is some correlation between density and metropolitan size—New York and Los Angeles are simultaneously two of the largest and densest regions—but the positive relationship holds even without these cases. And even the small region of Las Vegas demonstrates high accessibility, in part a function of its development density.

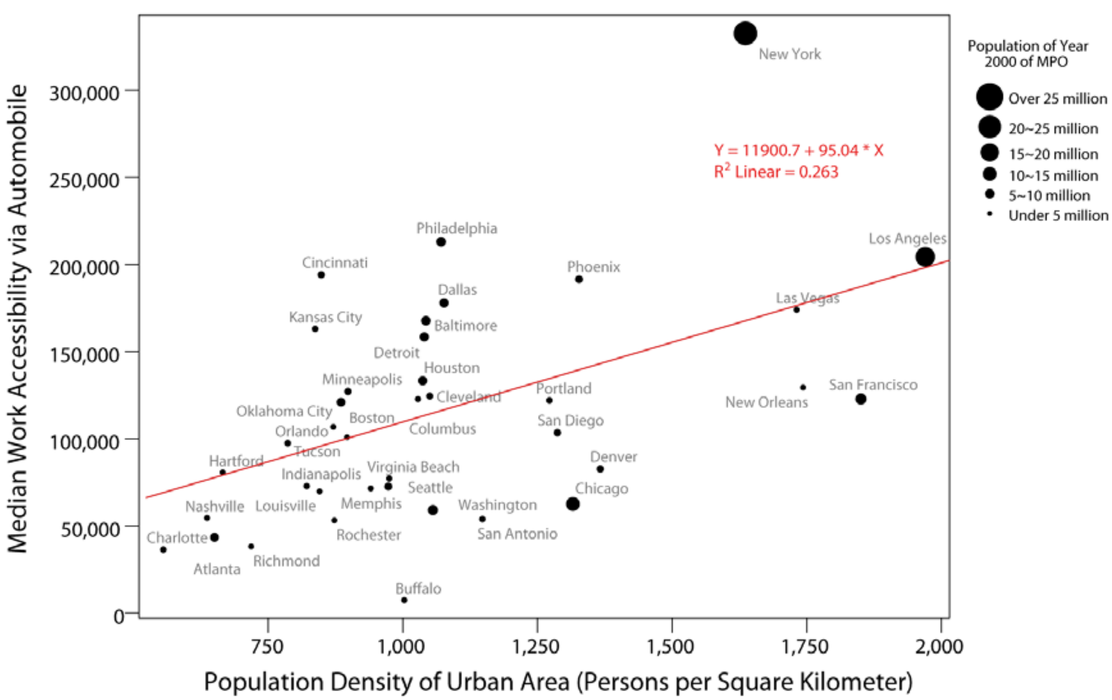


Figure 14: Median Work Accessibility by Automobile by Urbanized Area Density

In order to explore further the relationship between density and accessibility, metropolitan areas were paired on the basis of population size, and the distribution of accessibility analyzed between the two regions. For example a pairing of metropolitan Washington, D.C. with the (considerably denser) San Francisco Bay Area (Figure 14 and Figure 15) reveals similar levels of accessibility at the low end (the 1st percentile household – 99% of households in either region have higher levels of accessibility) and the high end (e.g., the 99th percentile household). The rest of the distribution reveals a higher accessibility for the San Francisco area; for example, with an accessibility score of over 100,000, the median Bay Area resident enjoys nearly double the accessibility of his or her Washington, D.C. counterpart. Though the horizontal axis in these graphs is ordered simply by population percentile of the accessibility score, it has somewhat of a geographical interpretation: since accessibility generally declines in concentric rings radiating outward from the center of the region, households at the low end of the distribution tend to reside in peripheral areas, while those at the high end live at the center. The median household would in most cases be a suburban resident.

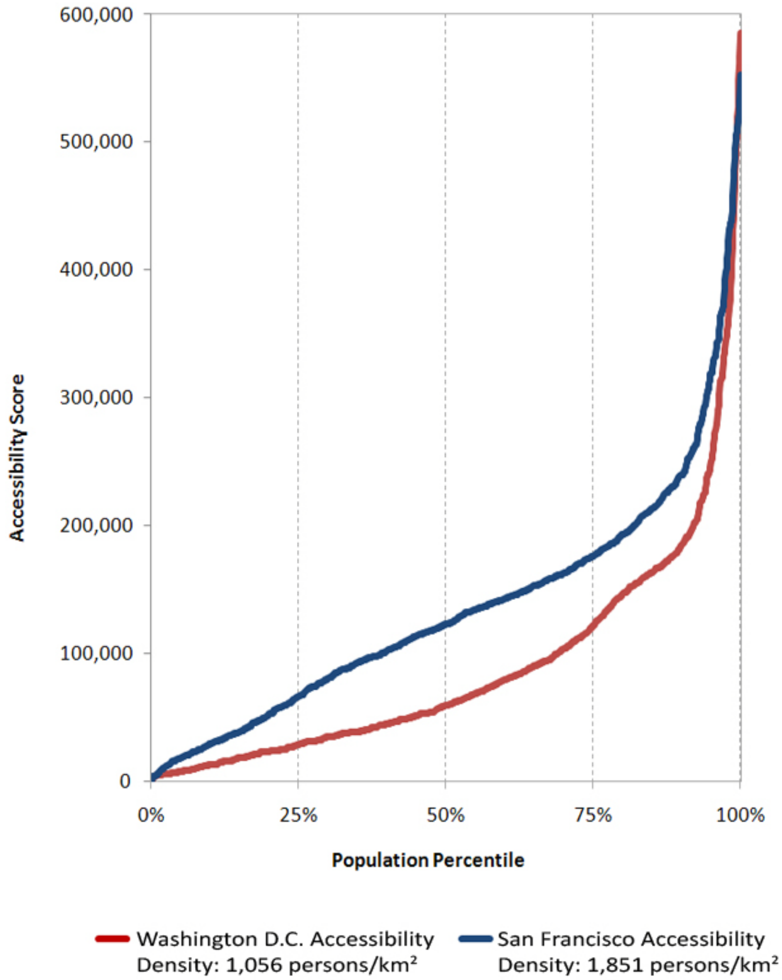


Figure 15: Population Distribution of Work Accessibility by Auto, San Francisco and Washington DC Metropolitan Areas

Accessibility differences between the two regions may be decomposed (as described above) into a proximity component and a speed component. This is accomplished by transforming the speed distribution of San Francisco into that of Washington, DC. A new set of accessibility indicators are calculated for San Francisco, using travel times derived from Washington speeds. Figure 14 graphs the transformed accessibility curve together with the original curves. The speed-related advantage to San Francisco is shown as the shaded area between the top and bottom curves; the proximity-related advantage to Washington is represented by the cross-hatched area below the bottom curve.

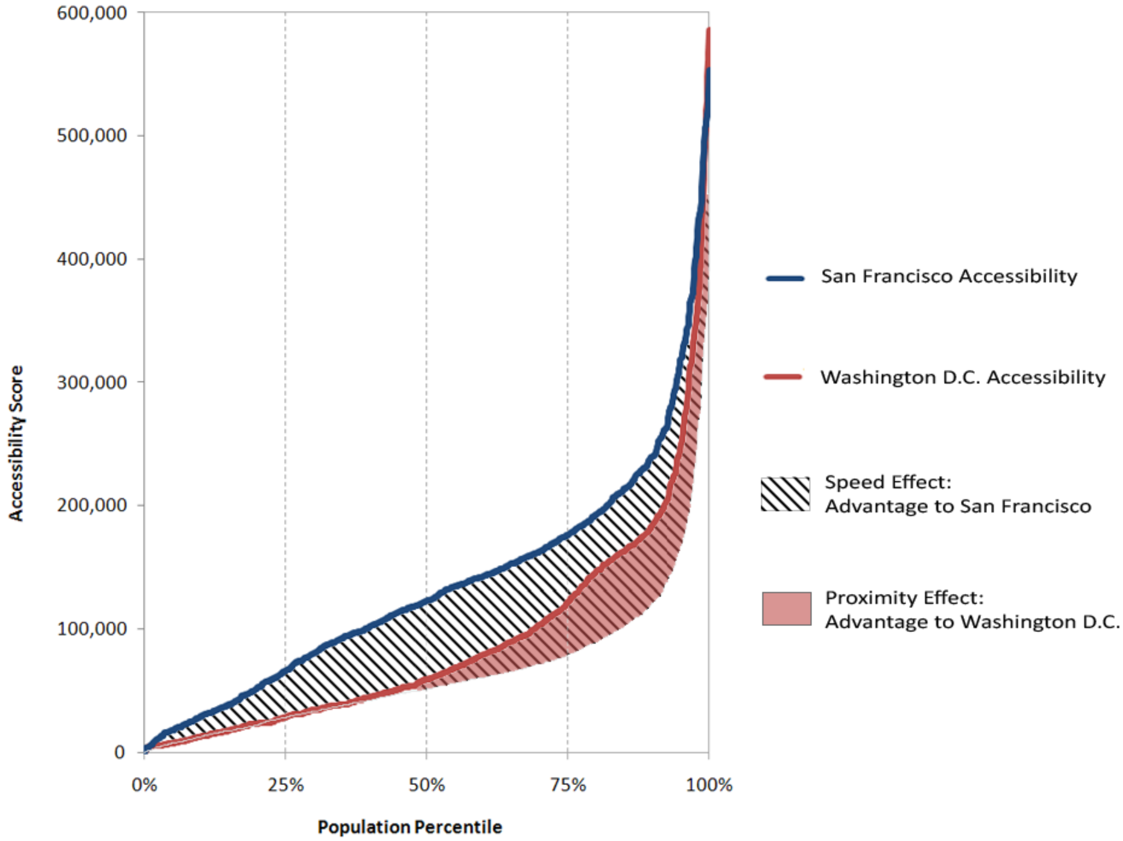


Figure 16: Decomposition of Accessibility Differences between Metropolitan San Francisco and Washington, D.C.

Notwithstanding the greater density of the San Francisco Bay Area, Washington D.C. demonstrates both a proximity advantage and a speed disadvantage. Given the greater magnitude of the speed disadvantage of Washington D.C., the conclusion is that the potential accessibility benefit of greater proximity was squandered by poor mobility—in this case automobility, since the accessibility metric is automobile based. In this case, the accessibility outcome is consistent with traditional mobility-based transportation planning; poor mobility has degraded the accessibility of what might otherwise be a highly accessible metropolitan area.

This relationship of speeds and accessibility is not universal, however, as illustrated by a similar decomposition of accessibility differences between another pair of similarly sized metropolitan areas: Philadelphia and Houston (Figure 17). Philadelphia enjoys a considerable accessibility advantage over Houston for most of the population distribution, notwithstanding the similar densities of the regions overall (1038 people/km^2 for Houston, 1070 for Philadelphia). A decomposition of the accessibility between the two regions reveals that Houston enjoys a considerable speed advantage over Philadelphia, but suffers from a proximity disadvantage. Notably, the proximity disadvantage exceeds the speed advantage, generating an accessibility disadvantage for Houston overall. While the Washington-San Francisco comparison was consistent with a mobility-based view of planning, this Houston-Philadelphia provides a counter-example: Houston accessibility suffers when compared to Philadelphia despite its faster travel speeds.

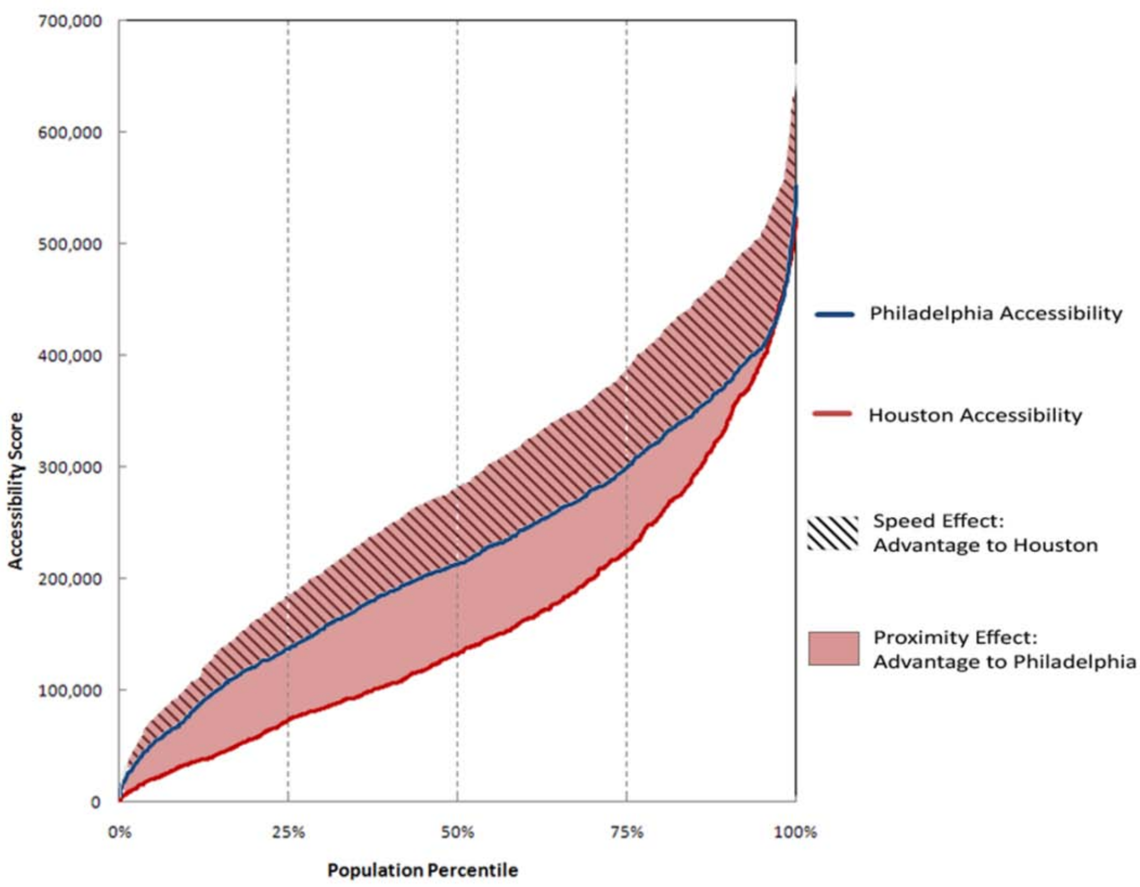


Figure 17: Decomposition of Accessibility Differences between Metropolitan Philadelphia and Houston

Needless to say, if metropolitan region "A" enjoys both a speed and a proximity over region "B" it will demonstrate higher accessibility overall. This is the case with New York when compared with Los Angeles (Figure 18). New York enjoys a slight speed advantage, a considerable proximity advantage, and overall accessibility advantage over Los Angeles for most of the population distribution. Ironically, New York was singled out as a particularly problematic case in a recent book entitled *Mobility First* (Staley 2008). Notwithstanding the serious congestion problems of New York City, its region presents the highest accessibility case of all regions studied (a function in part of its very large size). This case demonstrates the very different conclusions that are reached in transportation policy when the evaluation turns from mobility to accessibility; a region deemed to be mobility-deficient emerges as accessibility rich.

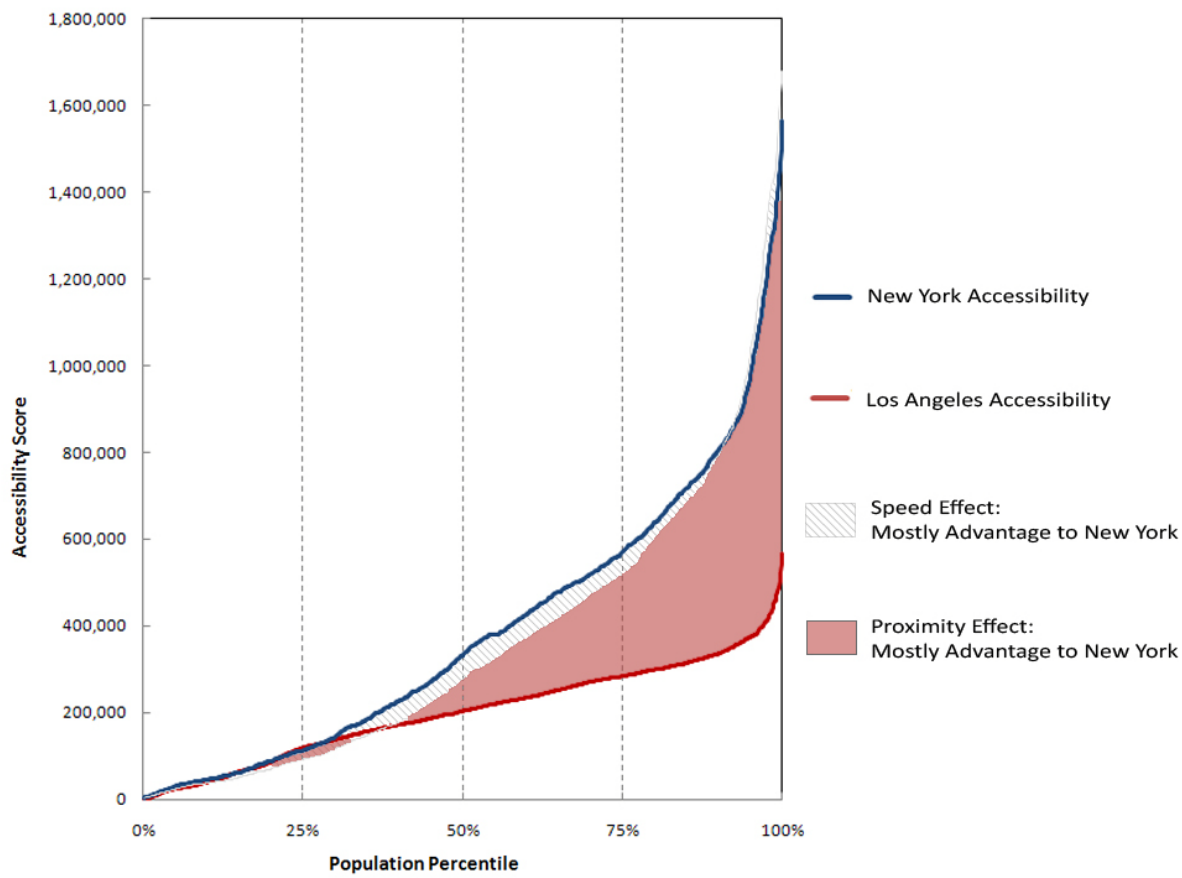


Figure 18: Decomposition of Accessibility Differences between Metropolitan New York and Los Angeles

Further comparisons of metropolitan regions paired for similar population are presented in Appendix A, which also provides transit-based comparison. These pairings tend to support the conclusions above regarding density as pertains to auto accessibility (though results regarding transit accessibility are much more mixed, with the lower density region edging out the higher-density in about half the cases).

Social Equity Analysis of Metropolitan Accessibility

The transportation planning and engineering professions have not yet put into practice sound methods for measuring and evaluating social equity, in part because they largely hold to mobility-centered views of policy. Accessibility-based measures are more suitable tools than mobility-based measures for social equity analysis because they properly place emphasis on people and their relationships to places, and because they capture the effects not only of transportation infrastructure but also the spatial arrangement of the destinations that are important to people in their day-to-day lives.

Methods of Comparing Social Groups by Accessibility

This study follows the common approach of calculating accessibility indicators separately by travel mode, using one indicator for travel by auto and another indicator for travel by transit. The reason for calculating separate indicators is primarily because the travel time difference between the modes is so substantial that to combine the modes into a composite accessibility index would be highly misleading. Because travel times between the modes as so considerable, travel mode is a decisive factor in evaluating accessibility among people. The ability to reach destinations varies substantially depending on whether a person can use an automobile or not.

The equity approach used here is to assign households to one of two accessibility conditions: either all persons in a household experience accessibility by auto, or all persons in a household experience accessibility by transit, depending on the availability of a vehicle to the household. Any household without a vehicle is presumed to be dependent on public transportation, and such a household experiences only transit accessibility. Conversely, any household with a vehicle available will experience auto accessibility. This is an assumption driven primarily by data availability and suffers from shortcomings. How someone in a household experiences accessibility is clearly more complicated than this assumption suggests. For example, people in carless households are not necessarily dependent on transit; they may share rides with car-owners or restrict their housing locations to be within walking distance of work. By contrast, people who live in a household with a car do not necessarily use that car. For instance, a household where the number of workers exceeds the number of cars may force some to rely on transit.

Social Groups and Data Sources

This section introduces an approach to evaluating the equity of accessibility distribution by (a) Vehicle Availability (households without vehicles compared to households with vehicles); (b) Race (restricted to the three races as defined by the Census Bureau of African Americans, Asians, and Whites); and (c) Household Income (three categories of Low, Medium, and High).

These separate analyses – by vehicle availability, race, and income – require data at varying geographic units from several sources, as summarized in Table 3 below. Both race and household income must be cross-tabulated with vehicle availability in order to assign households to either auto or transit accessibility. Vehicle availability is a household-level variable taken at the block-group level of geography from the 2000 Census of Population and Housing (U.S. Bureau of the Census, 2002). Household income is also a household-level variable, but in order to make a cross-tabulation with vehicle availability requires data at the geographic unit of a TAZ and from the 2000 Census Transportation Planning Package (CTPP). Race is not a household-level variable because members of a household may be of multiple races or ethnicities. But in order to cross-tabulate with vehicle availability (a household-level variable) members of a household are assumed to share the race of the householder.[4] Furthermore, race is not available cross-tabulated with vehicle availability from the CTPP, but it is available at the census-tract level from the 2000 Census of Population and Housing (U.S. Bureau of the Census, 2002). TAZ-

[4] In census data collection, one person in each household is designated as the householder. The householder is usually the person in whose name the home is owned, being bought, or rented.

level accessibility values are assigned to block groups and census tracts with a spatial join procedure in Geographic Information Systems (GIS).

Table 4. Summary of Equity Analyses and Data Sources

Analysis	Number of Metropolitan Cases	Comparison Groups	Geographic Unit	Data Source
Vehicle Availability	27	Households with no vehicle available; Households with a vehicle available	Block Group	2000 Census of Population and Housing, Summary File 3, Table H44
Race	26	African American Asian White	Census Tract	2000 Census of Population and Housing, Summary File 3, Tables HCT33A, HCT33B, HCT33D
Household Income	25	Low Medium High	Transportation Analysis Zone	2000 Census Transportation Planning Package, Part 1, Table 079

Table 4 also shows the number of metropolitan cases that have sufficient data for each analysis. Collecting data from MPOs on transit travel proved more difficult than for automobile travel. Because transit data are central to equity analysis, the lack of sufficient transit data limits the number of cases available for analysis, ranging from 25 cases (for the analysis of household income) to 27 cases (vehicle availability).

Evaluating accessibility on household income presents a challenge because the “cost of living” varies substantially by metropolitan region; a $50,000 annual income means something very different to a household in New York than it does to a household in Des Moines. This study’s approach is to divide all households of a region into three categories of “Low”, “Medium”, and “High,” with each category containing about one-third of the households in a metropolitan region. The three categories are defined on a relative basis with respect to a particular region’s income distribution. Under this relative approach to defining income categories, the cutoff values between categories must go up as the average, or median, income in a region increases, on the assumption that the resources necessary to participate in that region’s social life increase as well.

This approach facilitates comparison of social groups on income within a metropolitan region, but the categories themselves are not strictly comparable across metropolitan regions. Table 5 provides the income groupings for the metropolitan regions.

Table 5. Definition of Low-, Medium-, and High-Income, by Income Category, by Metropolitan Region

MPO \ Income Category	<$10,000	$10,000-$14,999	$15,000-$29,999	$30,000-$39,999	$40,000-$49,999	$50,000-$59,999	$60,000-$74,999	$75,000-$99,999	$100,000-$124,999	>$125,000
San Francisco	4%	7%	18%	26%	35%	44%	56%	71%	81%	100%
Boston	8%	13%	27%	36%	45%	54%	65%	79%	87%	100%
Chicago	5%	8%	22%	33%	44%	54%	67%	81%	89%	100%
Philadelphia	5%	9%	23%	34%	45%	54%	67%	81%	89%	100%
Atlanta	6%	10%	25%	36%	46%	56%	68%	82%	89%	100%
Minneapolis-St. Paul	5%	10%	25%	36%	46%	56%	69%	83%	90%	100%
Denver	6%	10%	26%	37%	48%	58%	70%	83%	90%	100%
Seattle	6%	11%	27%	38%	49%	59%	71%	85%	91%	100%
New York	10%	16%	31%	40%	49%	57%	68%	80%	87%	100%
Detroit	8%	13%	29%	40%	50%	59%	70%	83%	91%	100%
Baltimore	9%	13%	29%	41%	51%	60%	72%	84%	91%	100%
Dallas	7%	11%	29%	41%	52%	61%	72%	84%	90%	100%
Los Angeles	9%	15%	33%	44%	54%	62%	73%	84%	90%	100%
Houston	9%	14%	33%	45%	55%	63%	74%	85%	91%	100%
Richmond	8%	12%	30%	42%	53%	63%	75%	87%	93%	100%
Portland	7%	12%	29%	41%	53%	63%	75%	87%	93%	100%
Charlotte	7%	12%	30%	42%	54%	64%	75%	87%	92%	100%
Cincinnati	8%	14%	32%	44%	55%	64%	76%	87%	93%	100%
Columbus	8%	13%	31%	44%	55%	64%	76%	87%	93%	100%
Las Vegas	7%	12%	31%	44%	56%	66%	77%	88%	94%	100%
Cleveland	9%	15%	35%	47%	58%	67%	78%	88%	94%	100%
Kansas City	8%	14%	33%	46%	57%	67%	78%	89%	94%	100%
Memphis	11%	17%	37%	49%	60%	68%	79%	89%	94%	100%
Virginia Beach	8%	14%	33%	47%	58%	69%	80%	90%	95%	100%
Tucson	10%	17%	40%	54%	65%	73%	82%	91%	95%	100%

Note: Green indicates low-income households; yellow indicates medium-income households; pink indicates high-income households. Percentages represent the share of households with an annual income of less than the upper bound of the corresponding income category. Groupings aim for the nearest cut points for 33.3 percent and 66.7 percent.

Accessibility Equity, Vehicle Availability, and Residential Location

Lack of access to a private vehicle in a metropolis of the United States constitutes a severe accessibility disadvantage relative to those with cars (Blumenberg & Manville, 2004; Grengs, 2010). This section evaluates the degree to which "transit-dependent" households – including all persons who live in a household with no private vehicle available – experience accessibility compared to their counterparts who can drive.

Three main factors contribute to the equity of the accessibility distribution among a metropolitan region's residents. First, regions where transit accessibility is high relative to automobile accessibility will be more equitable than others. Second, regions with a small share of transit-dependent residents will be more equitable than regions with large shares of transit-dependent residents. Having access to a car is an advantage even in regions with exceptionally high transit accessibility. Finally, a region will be more equitable if a larger share of transit-dependent people is capable of living in zones where transit accessibility is high. Under this approach, land-use regulations and housing policies might contribute to improving transportation equity by relaxing restrictions on where people live.

This section focuses on the locational factor. Dependence on public transit usually constitutes an accessibility disadvantage; dependence on public transit while living where transit accessibility is low is a double burden. In this regard, Figure 19 shows the metropolitan regions sorted in increasing order of the share of transit-dependent households residing in the highest transit accessibility quartile. New York performs best on allowing transit-dependent households to avoid living where transit accessibility is lowest, with only about four percent of households with no vehicle available living in the lowest transit accessibility quartile. By contrast, in Tucson, one in five transit-dependent households resides in zones of the lowest transit accessibility quartile.

Note that the quartiles of transit accessibility are defined internally to each metropolitan area, such that the top quartile of Kansas City (for example) would represent much lower accessibility than the top quartile of New York City. This is to facilitate analysis of the capacity/desire of transit-dependent households to select the transit-accessible areas *within* their metropolitan region.

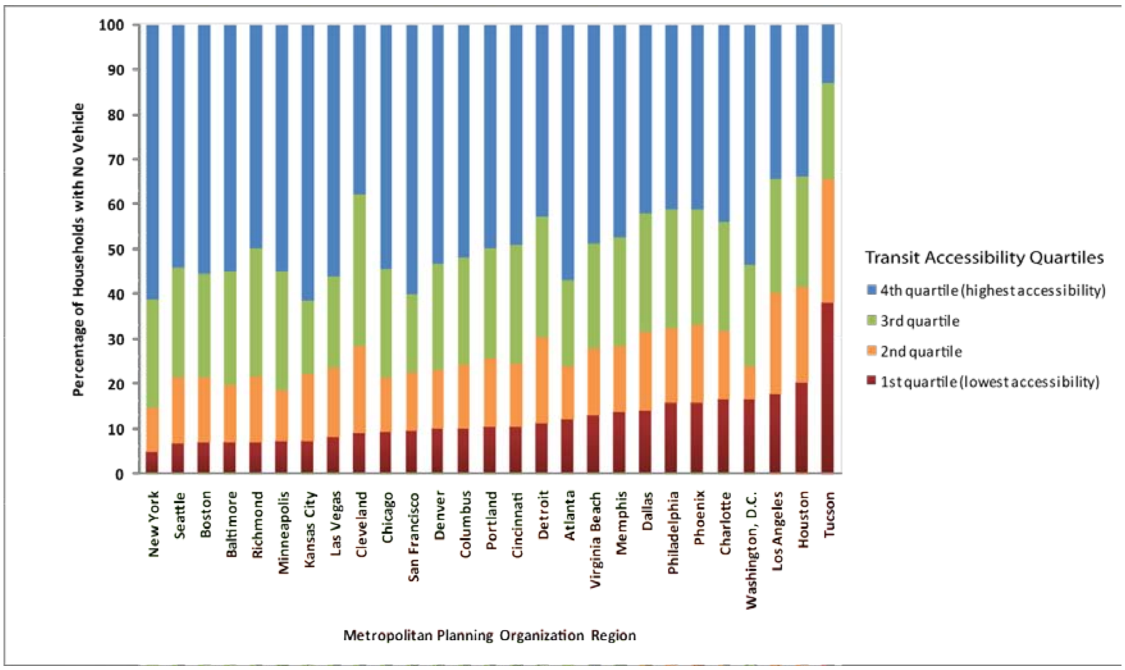


Figure 19. Mode-Location Mismatch: Share of Transit-Dependent Households Residing in Four Transit Accessibility Categories (sorted in increasing order on the lowest transit accessibility quartile)

People who are dependent on transit are not evenly distributed in metropolitan space but are typically concentrated near the metropolitan core (Glaeser, Kahn, & Rappaport, 2008; Grengs, 2010), precisely where transit accessibility tends to be high. To capture this (presumably desirable) effect, accessibility distributions of transit-dependent households are compared with those of the entire metropolitan population. Figure 20 is an illustration of the approach and compares three distributions of modes on accessibility to work: Line A (shown in red) is the distribution of the entire metropolitan population as it experiences transit accessibility; Line B (blue) is also a distribution of people as they experience transit accessibility, but rather than using the entire population this distribution is restricted to transit-dependent households (i.e., zero-vehicle households); and Line C (green) is the distribution of the entire metropolitan population as it experiences auto accessibility.

In Figure 20, if transit-dependent households were spatially distributed no differently than the general population, Line A and Line B would coincide. But because transit-dependent households tend to live more centrally than the general population, Line B is positioned above Line A, indicating that transit-dependent households experience higher transit accessibility than the population as a whole. The “Mode-Location Match Ratio” is defined here as Area 2 divided by the sum of Area 1 and Area 2. The larger the gap between Lines A and B, as a proportion of the total area under Line B, the higher the “mode-location match” – or the better the ability of transit-dependent households to locate themselves in zones of high transit accessibility; this represents the gain in accessibility generated by the locational choices of transit-dependent households (compared to transit accessibility of all households in the region).

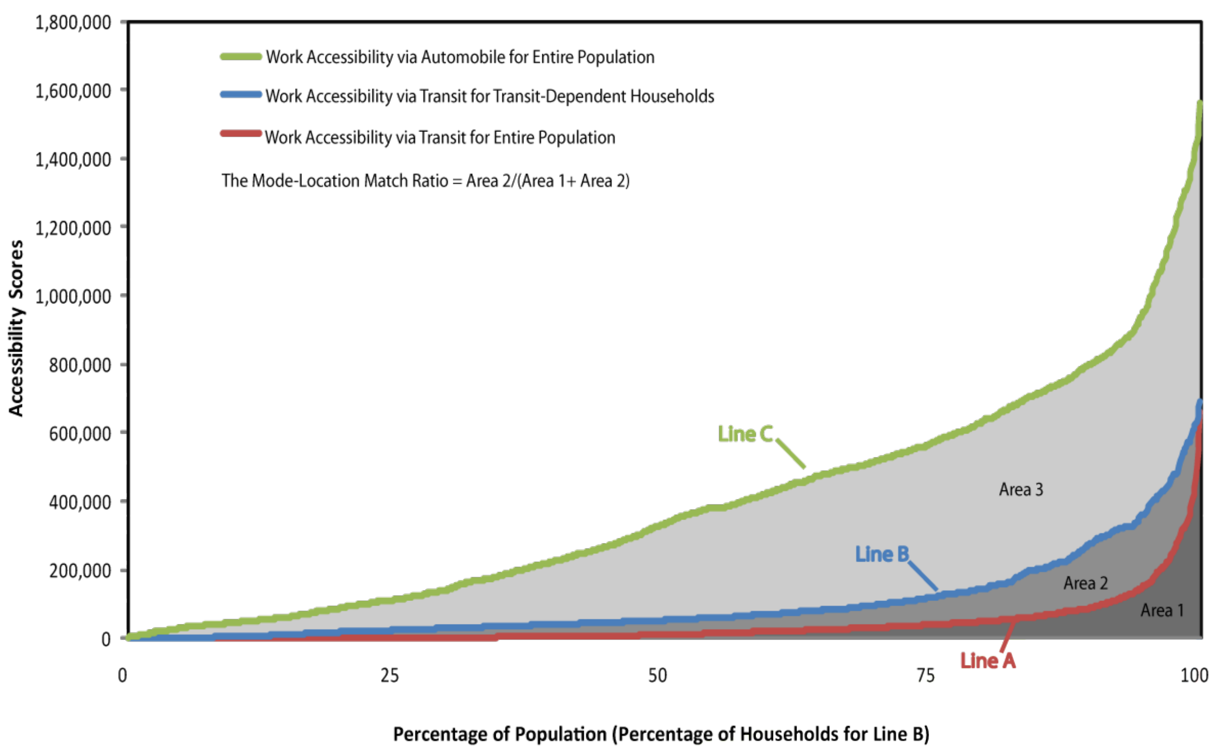


Figure 200. Illustration of the Mode-Location Match by Gap Analysis

The cases of New York (Figure 21) and Los Angeles (Figure 22), are used below to illustrate how the "Mode-Location Match Ratio" can be used to compare metropolitan regions by visual inspection. The gap between the blue line and the red line is much larger in New York (Figure 4) than it is in Los Angeles (Figure 5), constituting a larger proportion of the total area under the blue line. This larger proportion in New York suggests that transit-dependent households experience higher transit accessibility (relative to all households) in New York than their counterparts in Los Angeles. This result is presumably the combination of two factors: the *desire* of carless households to live in relatively transit-accessible zones within their region, and their *ability* to act on these preferences. The first factor is presumably in part a function of the total or relative transit accessibility offered by central zones; the latter would be related to the nature of the housing market—and notably, affordable housing supply—in zones of high relative transit accessibility.

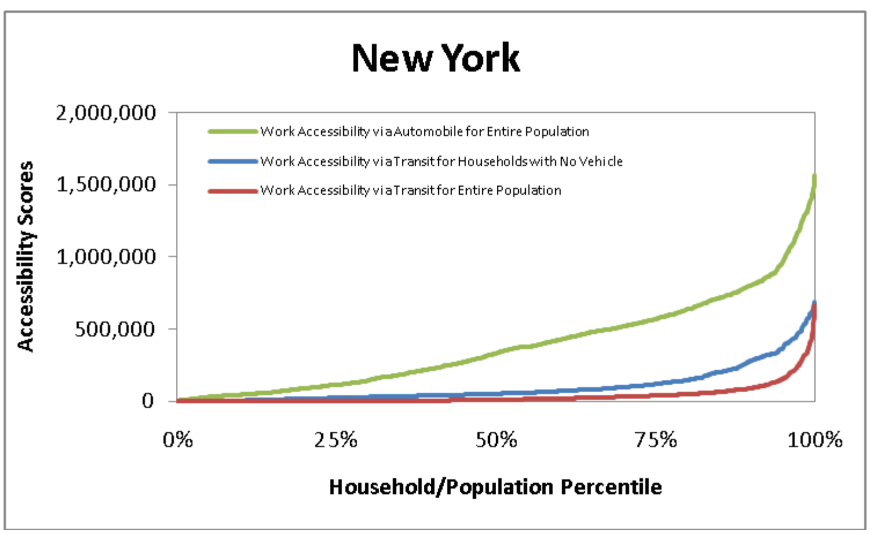


Figure 211. Mode-Location Match Gap Analysis: New York

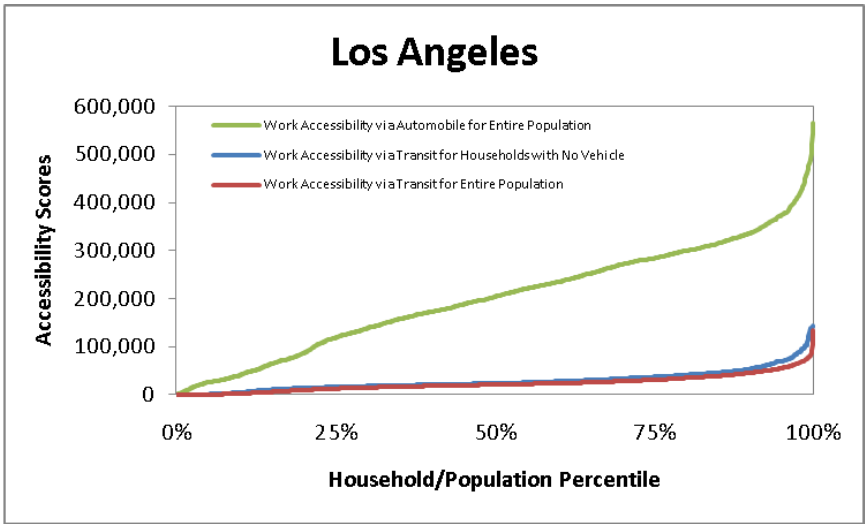


Figure 222. Mode-Location Match Gap Analysis: Los Angeles

Figure 23 summarizes the Mode-Location Match Ratio for 27 metropolitan cases sorted. By this measure, regions such as San Francisco and Seattle are performing best in terms of providing the ability of transit-dependent households to locate themselves in zones of high transit accessibility, while regions like Los Angeles and Houston are performing worse among this set of metros.

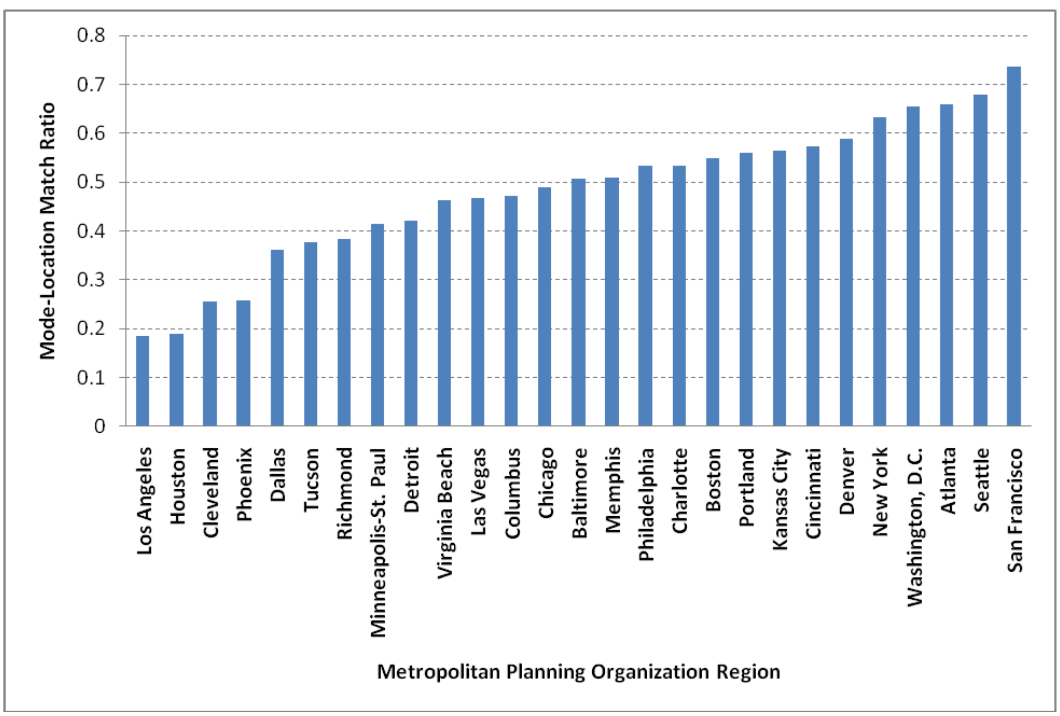


Figure 23. Inter-metropolitan Comparison of the Mode-Location Match Ratio

The set of figures showing the gap analysis for the 27 metropolitan regions for which sufficient data were available are included in Appendix G.

Accessibility Equity and Race

Several dimensions of the accessibility concept used in this study are known to vary considerably by race. Racial minorities tend to own fewer cars and rely more heavily on public transit (Pucher & Renne 2003), suggesting a disadvantage in mobility and, by extension, in accessibility. Racial minorities – and in particular, African Americans – are also not evenly spread throughout metropolitan space; they tend to be disproportionately located at the urban core of many metropolitan regions resulting in part from exclusionary zoning practices and historical racial discrimination in housing markets (Holzer 1991, Kain 1992, Massey and Denton 1993, Preston 1999). Residing in a central position in metropolitan space may be an advantage in accessibility. Whether a locational advantage is enough to offset the mobility disadvantages experienced by racial minorities is an open question. For instance, to be transit-dependent is ordinarily a substantial disadvantage in accessibility. But some metropolitan regions may provide transit service at a level that nearly compensates for this disadvantage. Or, some metropolitan regions may offer more flexibility in where racial minorities are capable of, or comfortable with, living, thus allowing people in need of good transit service the option of living in accessibility-rich places. This section aims to identify the combinations of land-use forms and transportation infrastructure that may be associated with benefits for racial minorities in accessibility terms. Analysis of accessibility by race can be carried out for any census-defined groupings by race. This section illustrates an approach by using only the three groups of Asian, Black, and White. Figure 24 shows how the three racial groups compare in the New York region. Asians as a group experience higher accessibility than the other two groups. Blacks and Whites are similar through most of the distribution, except for a small segment where Blacks are advantaged in the medium to high range of accessibility.

Consider the contrast between the shapes of the two lines for Blacks and Whites. For White households, the line proceeds in a fairly smooth rise, suggesting that accessibility is evenly spread among whites: about half of whites enjoy high accessibility, and about half of whites experience low accessibility. By contrast, for Black households, the line has a small hump in the middle, somewhat in the shape of an ‘S’. Blacks tend to experience either of two extremes in accessibility – either high or low – with little medium-level accessibility in between. The low extreme in accessibility among Blacks is likely due to their disproportionate dependence on transit. The high extreme in accessibility among Blacks can be explained by their central location.

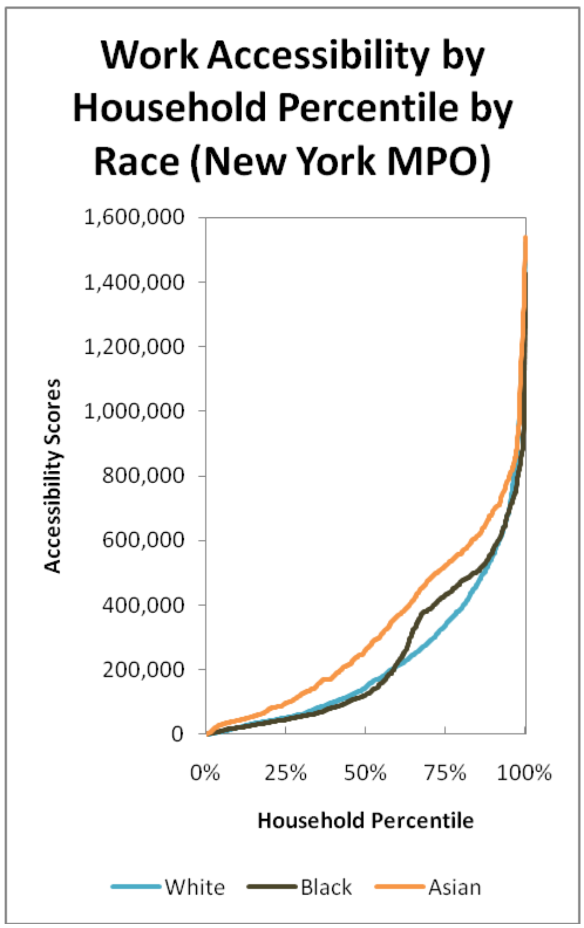


Figure 24. Work Accessibility by Race, New York

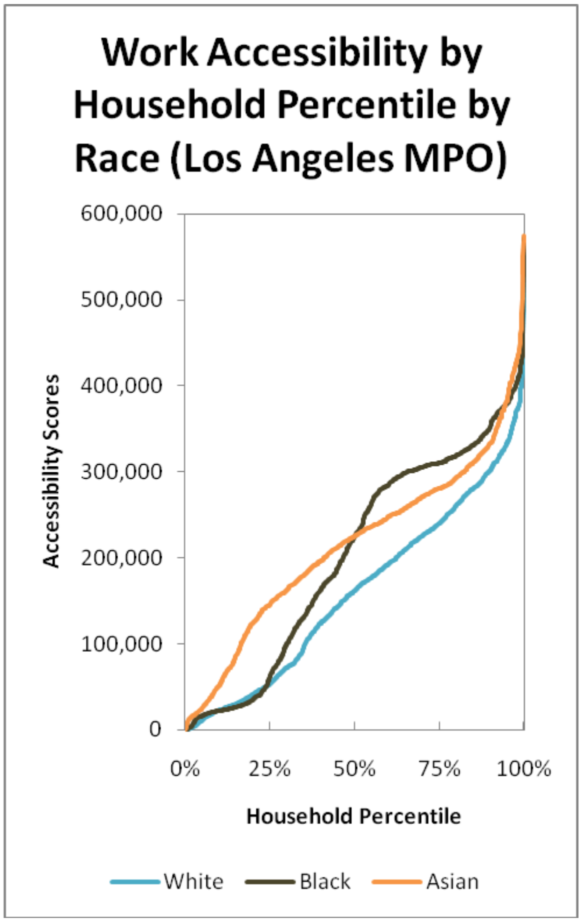


Figure 255. Work Accessibility by Race, Los Angeles

The case of Los Angeles, shown in Figure 25, offers a contrast to that of New York in the comparison of Blacks and Whites. In Los Angeles, African Americans tend to experience higher accessibility than Whites through most of the distribution, a pattern that is substantially different than in New York and possibly due in part to the differences in degree of centrality among Blacks in Los Angeles compared to New York. The difference in car-ownership rates between Blacks and Whites also probably plays an important role in explaining the variation found in the figures for New York and Los Angeles in the figures above. For example, as shown in Figure 26, a substantially larger share of African Americans in Los Angeles lives in households with vehicles available when compared to their counterparts in New York. Furthermore, the gap in vehicle availability between Blacks and Whites is considerably smaller in Los Angeles than in New York. It is likely that the advantage that Black Los Angelinos experience compared to

Whites, as shown in Figure 25, is driven in large part by high Black vehicle-availability rates, especially if a large share of metropolitan blacks are living in central locations in Los Angeles.

The results show that Blacks as a group tend to experience an advantage in accessibility compared to Whites, at least for the cases of Los Angeles and New York. This finding may run counter to the expectations of some. Indeed, the conventional understanding in social science literature is that racial minorities are disadvantaged in getting to opportunities in the United States because a growing share of metropolitan destinations are located in distant suburbs while minorities live near the center (de Souza Briggs 2005, Dreier, Mollenkopf, & Swanstrom 2004). Yet, from an accessibility perspective, to be centrally located is to be positioned near a wider range of opportunities than anywhere else in a region. There are several reasons why measuring accessibility by race would be important, even if the vulnerable group is found not be disadvantaged. First, taking an accessibility-based approach to equity analysis helps us see that the accessibility that Blacks experience tends to result from systematically different reasons than for Whites, particularly in auto availability rates and residential location. Monitoring changes in such variables are important from a public policy perspective. Second, the finding that Blacks are advantaged in Los Angeles and New York is not universal. Several cases noted below show the opposite result and discovering explanations for these different outcomes would be useful next research steps. Third, the finding is consistent with a central question that motivated this study: Are suburbs a low-accessibility urban form? Whites live disproportionately in low-density communities and they may be paying a price in the form of low accessibility for doing so, consistent with land-market theories that suggest that some households willingly trade-off higher transportation costs in exchange for larger homes and lots at distant locations (Alonso 1972). Seen in this way, differences in the matter of choice between Blacks and Whites are important to recognize in evaluating accessibility outcomes.

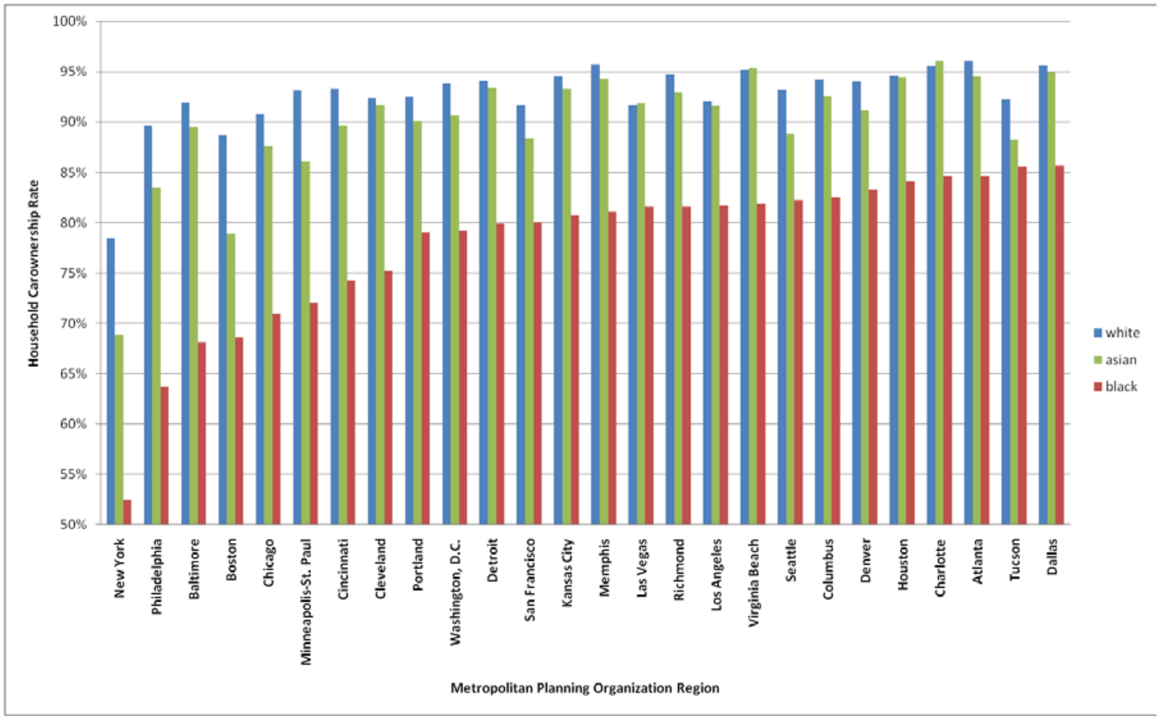


Figure 266. Intermetropolitan Comparison of Vehicle-Availability Rates, by Race (sorted in increasing order of Blacks)

In contrast to the findings in Los Angeles in New York, several metropolitan regions reveal patterns of accessibility disadvantage for Blacks. For example, Cleveland (Figure 27) is an example where African Americans are severely disadvantaged throughout the entire accessibility distribution. Boston and Philadelphia (Appendix G), reveal similar patterns such that the accessibility disadvantage for Blacks is not only substantial in magnitude, but also in that the disadvantage runs through the full range of the percentiles. All three of these regions are places with relatively low vehicle-availability rates among Blacks (as shown in Figure 26), and yet other regions with comparably low vehicle-availability rates among Blacks – such as Chicago and Minneapolis-St. Paul – do not reveal an accessibility disadvantage to Blacks.

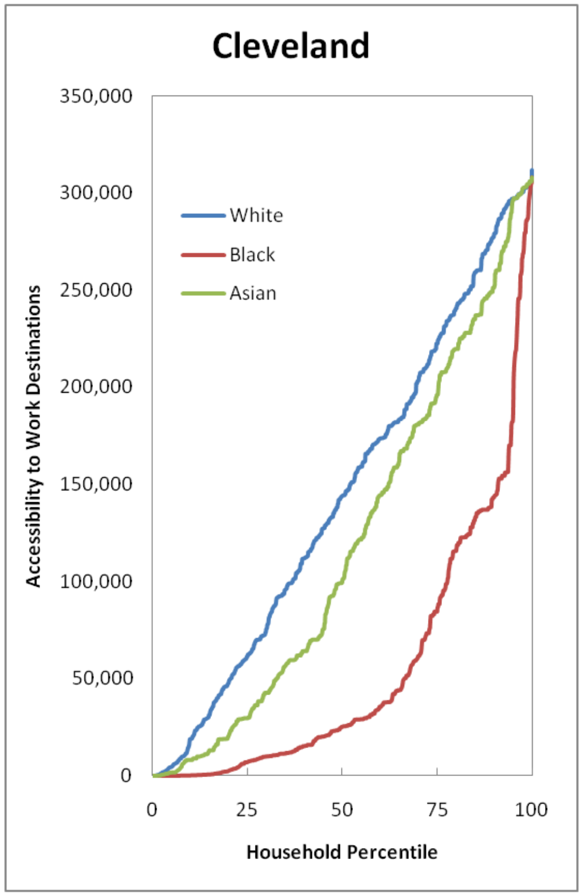


Figure 277. Work Accessibility by Race, Cleveland

A full set of figures showing work accessibility by race for the 26 metropolitan regions is included in Appendix H.

Accessibility Equity and Household Income

Evaluating accessibility in terms of income is important for reasons similar to that of race, since several dimensions of the accessibility concept vary systematically by income such as automobile ownership and residential location. The analysis by household income proceeds similarly to that of race, except that instead of three racial groups the three income categories of Low, Medium, and High are analyzed. A key difference among metropolitan regions on equity outcomes by income can be found in the varying rates of vehicle availability. Figure 28 illustrates how metropolitan regions vary in the difference between low-income households and high-income households on vehicle availability. For instance, in Dallas the difference between low-income and high-income households (represented by the blue and green bars respectively) is much smaller than in Baltimore. Because car-ownership plays such a key role in determining accessibility, it is likely that accessibility disparities between low- and high-income households will be more severe in Baltimore than in Dallas.

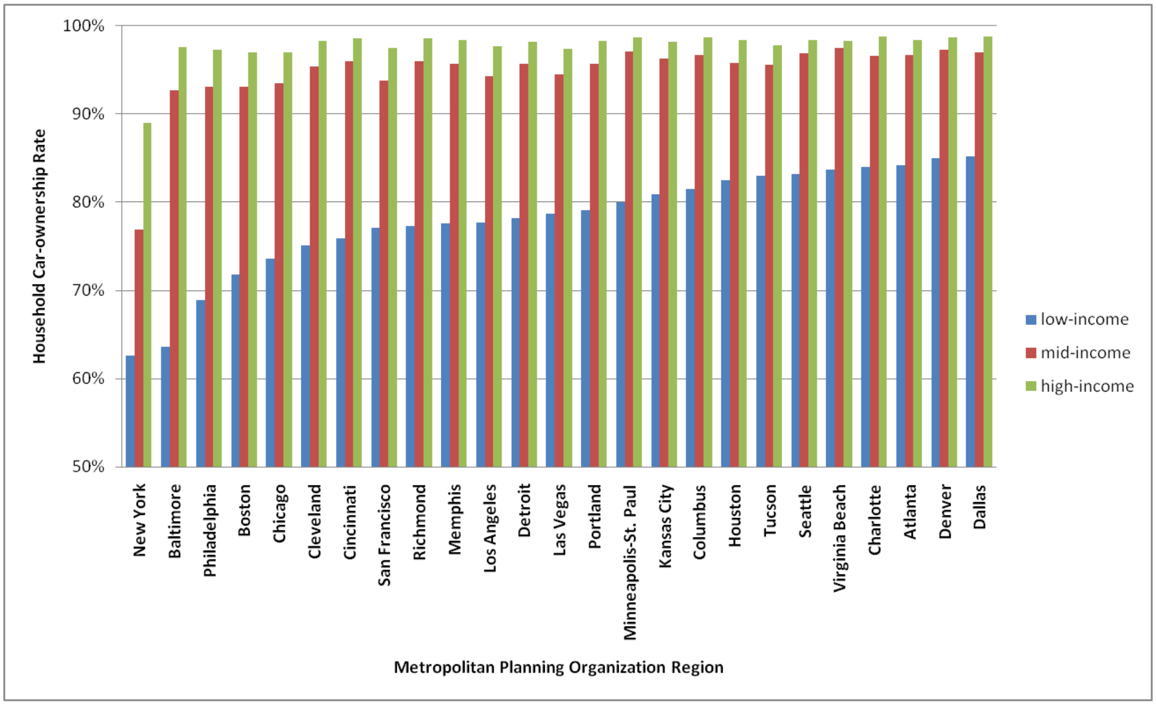


Figure 288. Intermetropolitan Comparison of Vehicle-Availability Rates, by Income (sorted in increasing order of the low-income category)

A comparison between Baltimore (Figure 29) and Dallas (Figure 30) reveals a greater disparity between low- and high-income households in Baltimore than in Dallas for the low end of the accessibility range (below the 50th percentile). Low-income households at the low end of the accessibility range are mainly car-owning households located in zones at the periphery of the region and transit-dependent households located anywhere in the region. However, the low-income line crosses the high-income line in both figures below. Although low-income households are disadvantaged in the low range of accessibility, at the high end of accessibility it is just the reverse: low-income households are advantaged relative to their high-income counterparts in the high accessibility range. Low-income households at the upper end of the accessibility range are likely car-owning households that experience a location advantage by residing near the center of the region compared to their high-income counterparts.

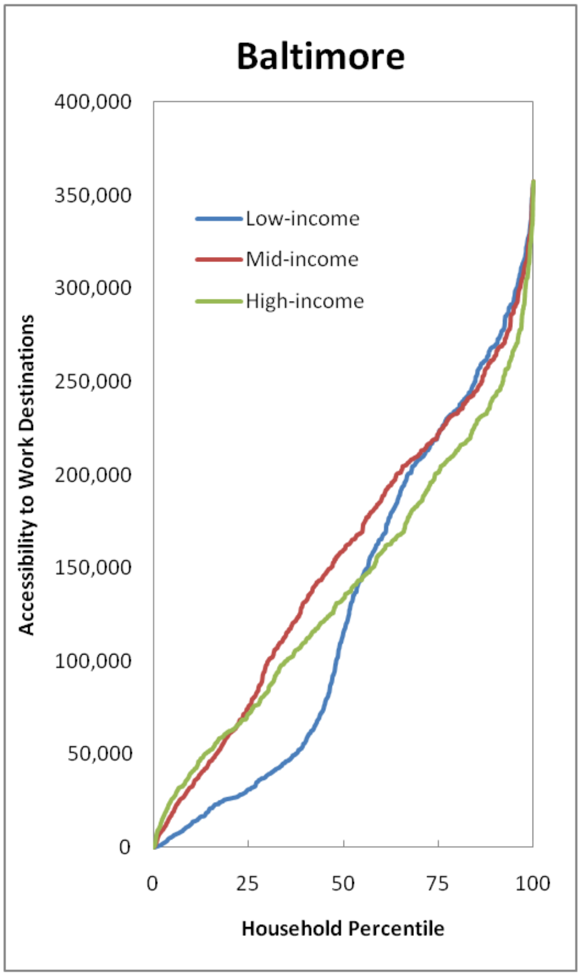


Figure 29. Work Accessibility by Household Income Categories, Baltimore

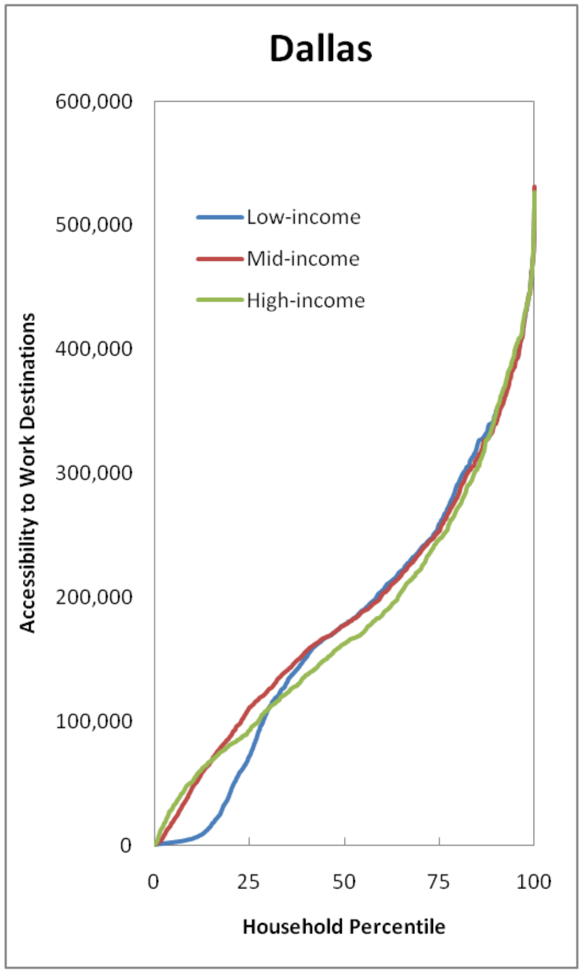


Figure 30. Work Accessibility by Household Income Categories, Dallas

Most of the metropolitan regions reveal patterns that are largely similar to the cases of Baltimore and Dallas illustrated here. Several cases are notable for unusual patterns (refer to Appendix G for the figures). First, some metropolitan regions have an unusually high disparity between low-income households and high-income households, including: Baltimore, Cincinnati, Los Angeles, Memphis, and Philadelphia. Second, several regions show a distinctly low disparity between low- and high-income households: Atlanta, Chicago, Minneapolis-St. Paul, and Seattle. Finally, although the case of Cleveland in the previous section revealed a dramatic disadvantage of Blacks compared to Whites, it does not show an unusually high disparity between low- and high-income households, indicating the importance of conducting equity analysis from a variety of perspectives.

A full set of figures showing work accessibility by household income for the 25 available metropolitan regions is included in Appendix I.

Accessibility: Equity and Urban-Form Dimensions

This study was designed in part to provide proof of the concept that intermetropolitan comparisons of accessibility are feasible. The metrics for comparing transportation outcomes between regions presented here stand in contrast to the strictly mobility-based evaluation approaches that typify traditional transportation planning. Accessibility metrics, while increasing in importance in transportation practice and research, are rarely used to compare between metropolitan areas; intermetroplitan comparisons are key to moving accessibility to a more central position in transportation policy. This is primarily because outcomes are frequently judged relative to others, with professionals and lay people both keen on asking how "we" are doing compared to other regions. Intermetropolitan comparison is also central to inferring the determinants of accessibility and accessibility change.

Two key obstacles to intermetroplitan comparison present themselves. The first is data availability and consistency. The principal data sets required for the current analysis are zone-to-zone travel times and travel flows for peak- and off-peak periods by each metropolitan area. On the one hand, these data are developed by virtually all large U.S. metropolitan planning organizations as part of their regional transportation planning process. But the data are collected with a hodge-podge of categories and definition. Much of the work of the current study was devoted to resolving intermetropolitan discrepancies in these datasets—a task that necessarily led to a comparison that is less reliable than it might be. Progress in accessibility evaluation will be facilitated by consistent definition of these model outputs across regions, and perhaps even the development of a nationwide repository of this information. This would have precedent in the National Transit Database, which requires standardized reporting on the part of transit agencies receiving federal funding—a standardization that facilitates meaningful comparison between agencies.

The second obstacle to intermetropolitan comparison of accessibility is methodological. Whereas in standard transportation planning practice an individual impedance distance-decay function is estimated for each region, this study has relied on a single pooled factor. The move is both necessary for intermetropolitan comparison and justified as a method, yet there are many approaches to estimating such a factor. Significantly higher or lower factors could not only raise or lower accessibility levels overall, but could alter the ordinal ranking between metropolitan areas.

The study focused substantively on two dimensions: equity outcomes and urban-form determinants of accessibility. In the equity realm, a long history of scholarship that evaluates equity in the delivery of urban services has resulted in highly mixed evidence, with some studies demonstrating that disadvantaged populations receive lower levels of services and others showing the opposite (Baer, 1985; Lucy, 1981; Mladenka, 1989; Rich, 1979). These and other studies make clear that evaluating equity is a highly complex exercise and the technical problems are severe.

Rarely is the concept of equity easily defined; it is highly contingent on a variety of factors. The best studies of equity in urban service provision use multiple indicators (Lucy, Gilbert, & Birkhead, 1977; Merget & Berger, 1982). One approach to evaluating equity is to describe patterns using a variety of measures across multiple dimensions, and then to test them against multiple evaluation criteria (Lucy, 1981).

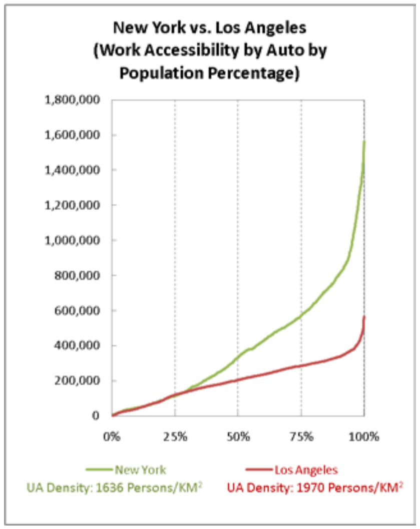
The analysis presented here has demonstrated that accessibility can be evaluated across multiple dimensions. Using three dimensions – vehicle availability, race, and income – patterns in the distribution of accessibility are described across metropolitan space. These patterns can be compared among metropolitan regions which, in this case, were primarily done by visual inspection of charted data. With some exceptions, there are few common outcomes running across all three dimensions. Notable exceptions are Boston, Cleveland, and Philadelphia, all of which suggest disadvantages in accessibility to work to work for African Americans and low-income households.

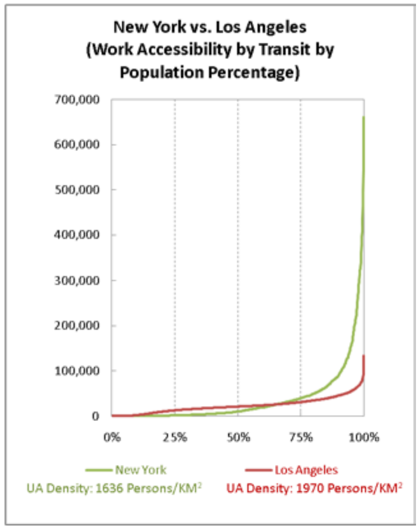
The concept of accessibility offers important insights into questions of social equity in transportation. In particular, the concept underscores the importance of residential location in a determining a household's ability to access opportunities. Transportation planners have typically focused on providing effective transportation infrastructure and services, essentially determining the spatial distribution of auto and transit accessibility. This study shows that even given a particular distribution of auto and transit accessibility, the location of carless people still matters. The ability of transit-dependent households to locate in transit-rich zones varies substantially from one region to the next, as this study has demonstrated by developing the Mode-Location Match Ratio. This and other indicators developed in this study can assis in the evaluation of transportation policy by tracking the distribution of transportation equity over time and by comparing (as demonstrated here) between regions.

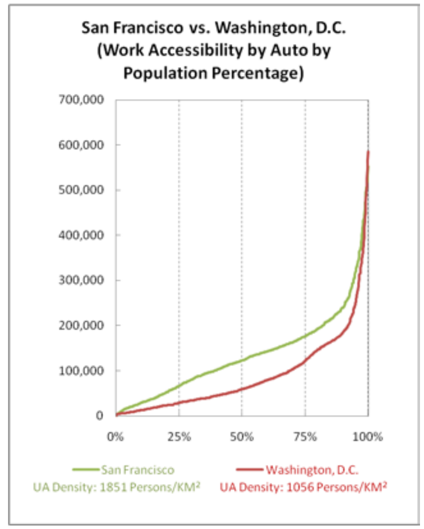
This study also seeks to demonstrate the relevance of accessibility metrics—and more broadly, accessibility-based transportation policies—to applied urban planning practice, particularly as such practice shapes urban form. Traditional mobility-based transportation evaluations tend to militate against denser development on the theory that dense land-use can lead to dense traffic and hence congestion. The analysis presented here does not dispute that density can increase congestion, but argues that such an outcome may well be accessibility-enhancing if the proximity advantages of density outweigh the congestion effects. Conversely, using land-use regulations to preclude such densification may degrade accessibility even as it strives to enhance (auto)mobility. This study supports the view that low-density regions tend to be regions of low automobile accessibility as well. In regions where higher densities are frequently viewed as a transportation disadvantage because of their impacts on congestion, this study suggests that these regions carry distinct transportation advantages when viewed in accessibility terms.

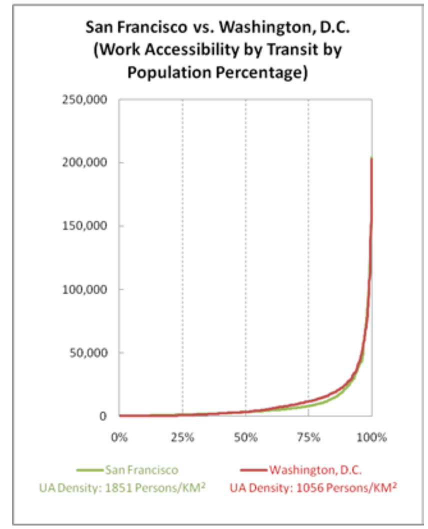
Ultimately, reform of transportation planning towards an accessibility-oriented practice is about getting more of what people want out of transportation. This perspective brings transportation planning practice in line with transportation research that finds that the demand for travel is derived from the demand for reaching destinations. The shift holds the promise of altering the tradeoff that has gripped transportation for years whereby transportation goals and environmental goals are viewed as being in competition. With compact metropolitan regions being associated with both lower VMT and higher accessibility, transportation and land-use policy may be able to promote both sets of values simultaneously.

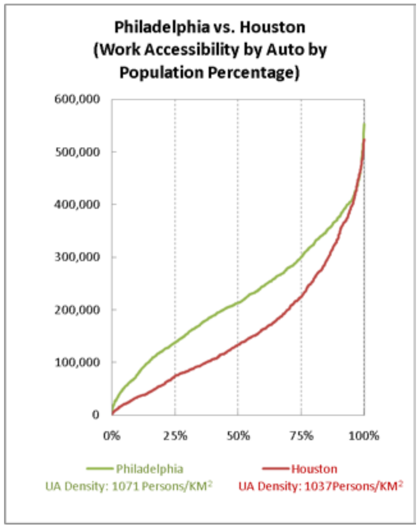
Appendix A: Work Accessibility Comparisons of Selected Paired Metropolitan Regions

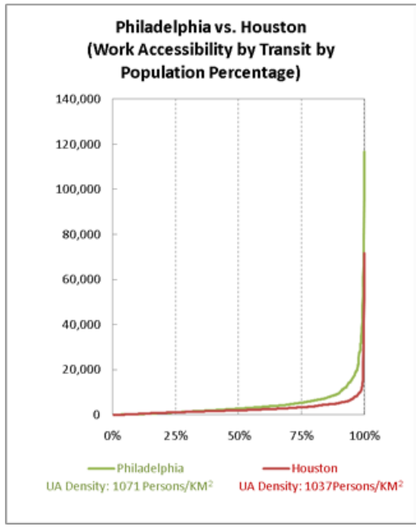


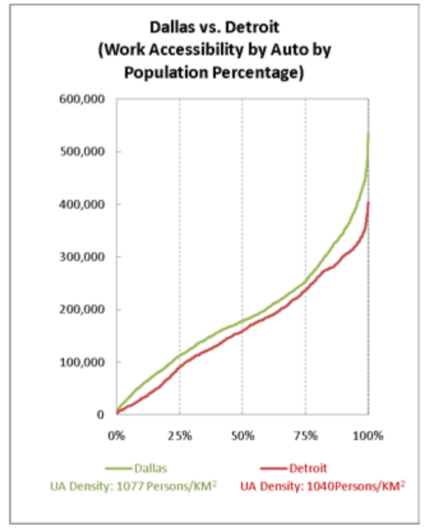


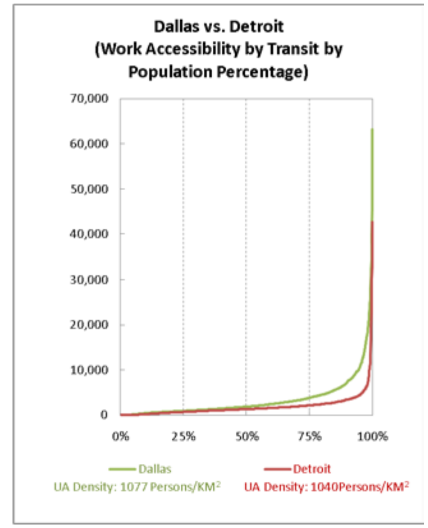


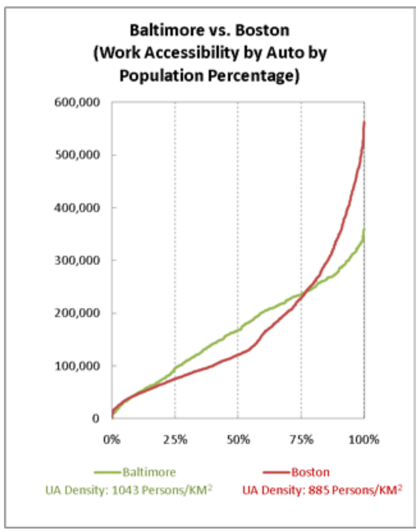


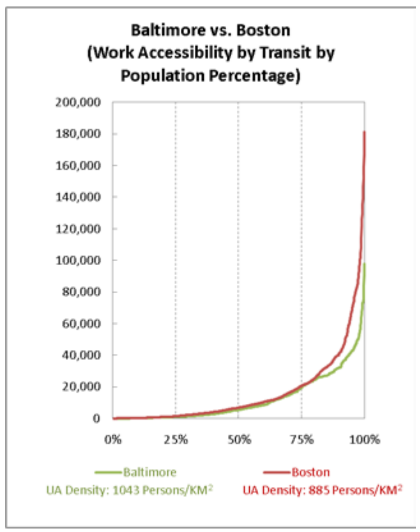

Philadelphia vs. Houston
(Work Accessibility by Auto by
Population Percentage)
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Philadelphia
Houston
UA Density: 1071 Persons/KM²
UA Density: 1037Persons/KM²

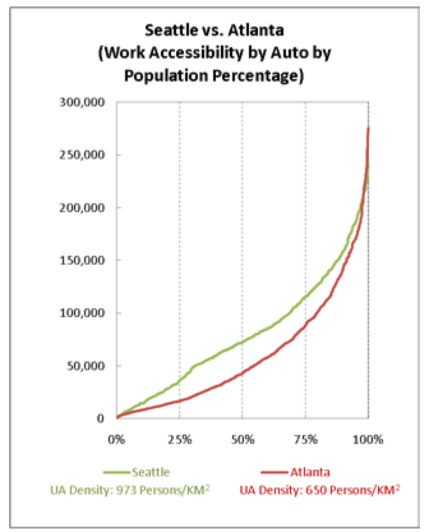

Philadelphia vs. Houston
(Work Accessibility by Transit by
Population Percentage)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Philadelphia
Houston
UA Density: 1071 Persons/KM²
UA Density: 1037Persons/KM²

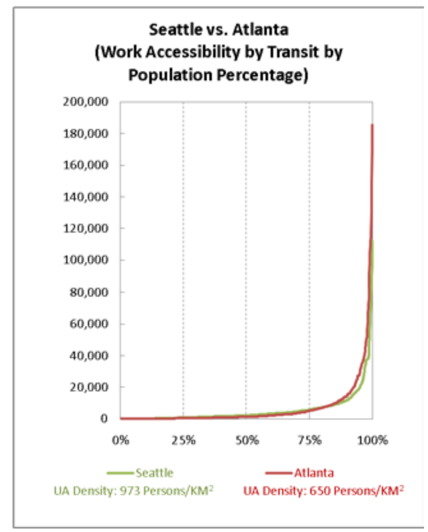

Dallas vs. Detroit
(Work Accessibility by Auto by
Population Percentage)
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Dallas
Detroit
UA Density: 1077 Persons/KM²
UA Density: 1040Persons/KM²

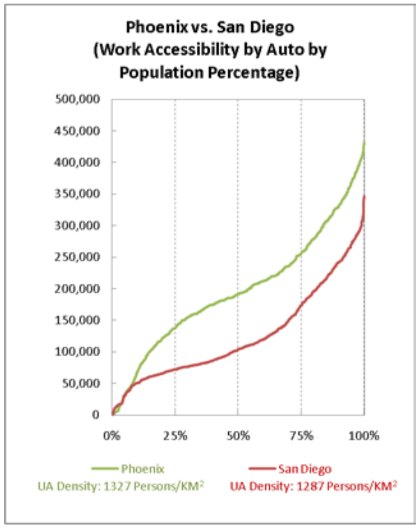

Dallas vs. Detroit
(Work Accessibility by Transit by
Population Percentage)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0%
25%
50%
75%
100%
Dallas
Detroit
UA Density: 1077 Persons/KM²
UA Density: 1040Persons/KM²

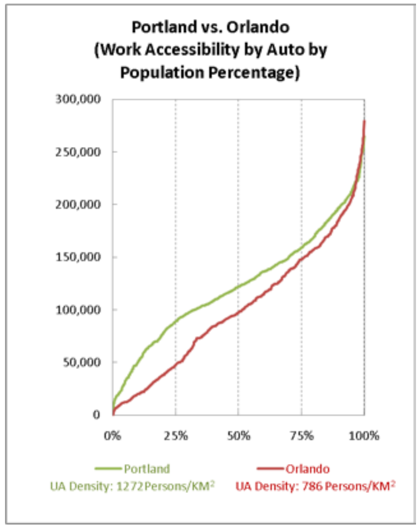

Baltimore vs. Boston
(Work Accessibility by Auto by
Population Percentage)
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Baltimore
Boston
UA Density: 1043 Persons/KM²
UA Density: 885 Persons/KM²

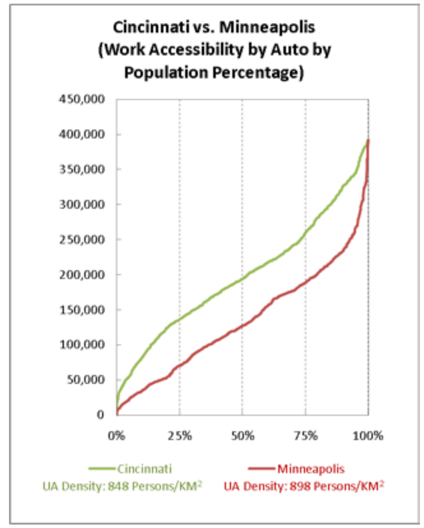

Baltimore vs. Boston
(Work Accessibility by Transit by
Population Percentage)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Baltimore
Boston
UA Density: 1043 Persons/KM²
UA Density: 885 Persons/KM²

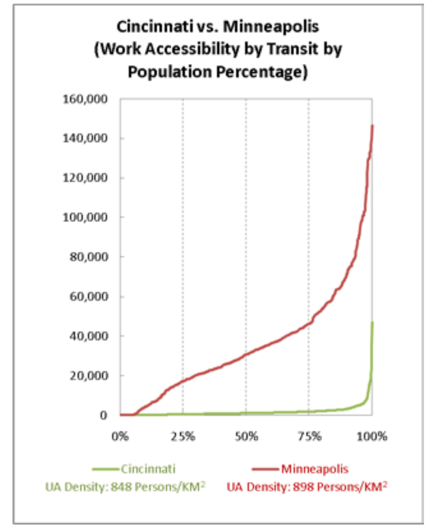

Seattle vs. Atlanta
(Work Accessibility by Auto by
Population Percentage)
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Seattle
Atlanta
UA Density: 973 Persons/KM²
UA Density: 650 Persons/KM²

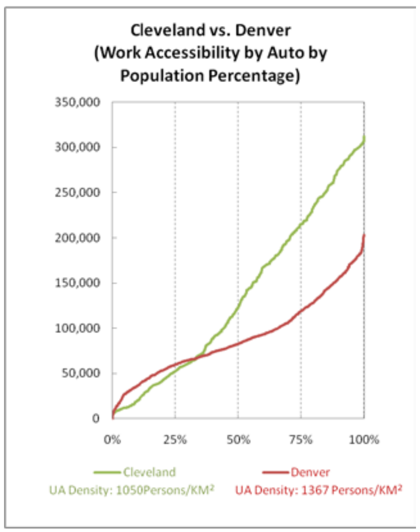

Seattle vs. Atlanta
(Work Accessibility by Transit by
Population Percentage)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Seattle
Atlanta
UA Density: 973 Persons/KM²
UA Density: 650 Persons/KM²

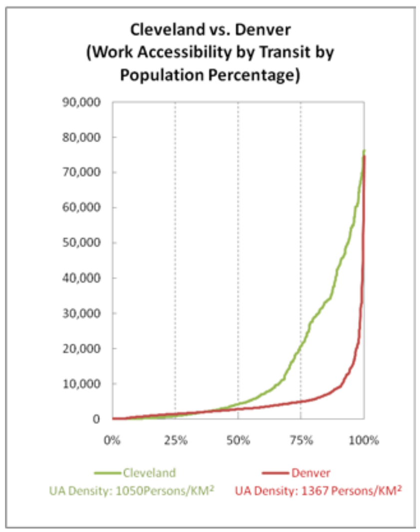

Phoenix vs. San Diego
(Work Accessibility by Auto by
Population Percentage)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Phoenix
San Diego
UA Density: 1327 Persons/KM²
UA Density: 1287 Persons/KM²

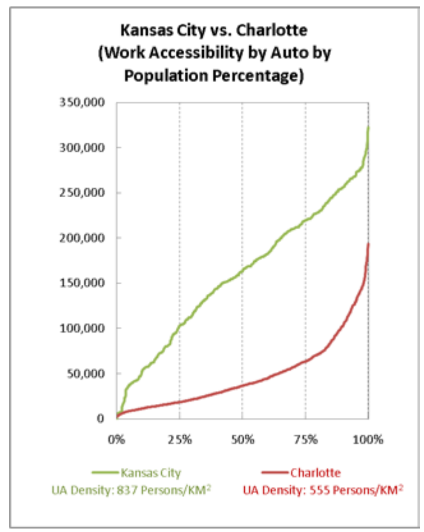

Portland vs. Orlando
(Work Accessibility by Auto by
Population Percentage)
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Portland
Orlando
UA Density: 1272 Persons/KM²
UA Density: 786 Persons/KM²

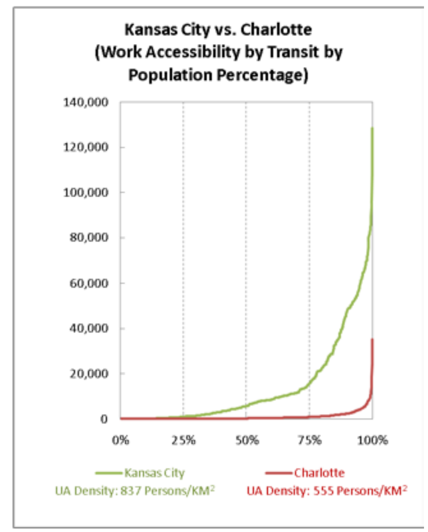

Cincinnati vs. Minneapolis
(Work Accessibility by Auto by
Population Percentage)
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Cincinnati
Minneapolis
UA Density: 848 Persons/KM²
UA Density: 898 Persons/KM²

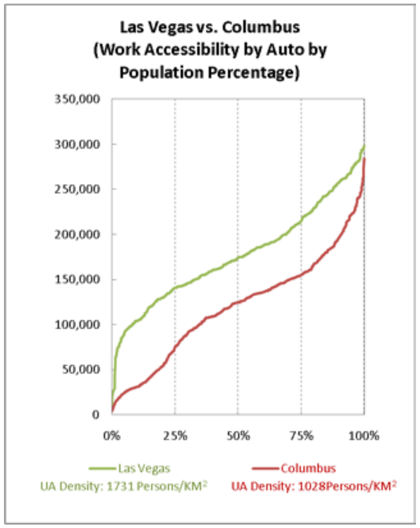

Cincinnati vs. Minneapolis
(Work Accessibility by Transit by
Population Percentage)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Cincinnati
Minneapolis
UA Density: 848 Persons/KM²
UA Density: 898 Persons/KM²

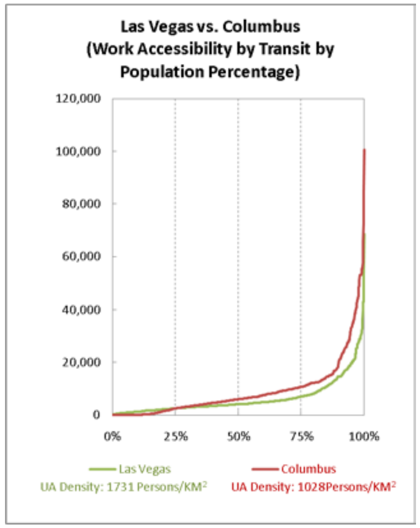

Cleveland vs. Denver
(Work Accessibility by Auto by
Population Percentage)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Cleveland
Denver
UA Density: 1050Persons/KM²
UA Density: 1367 Persons/KM²

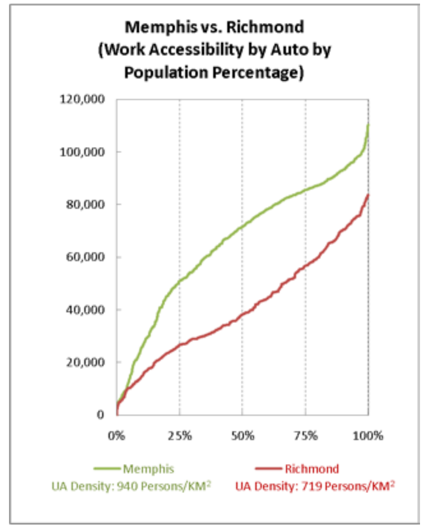

Cleveland vs. Denver
(Work Accessibility by Transit by
Population Percentage)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0%
25%
50%
75%
100%
Cleveland
Denver
UA Density: 1050Persons/KM²
UA Density: 1367 Persons/KM²

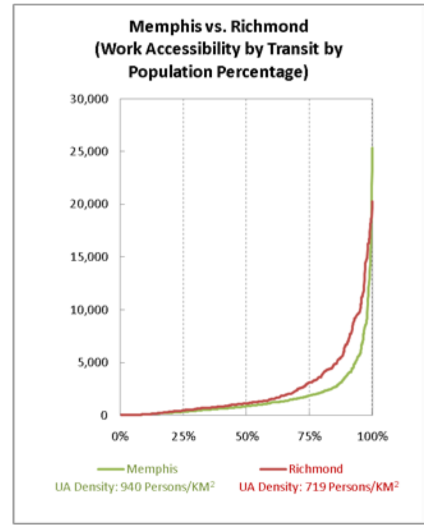

Kansas City vs. Charlotte
(Work Accessibility by Auto by
Population Percentage)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Kansas City
Charlotte
UA Density: 837 Persons/KM²
UA Density: 555 Persons/KM²

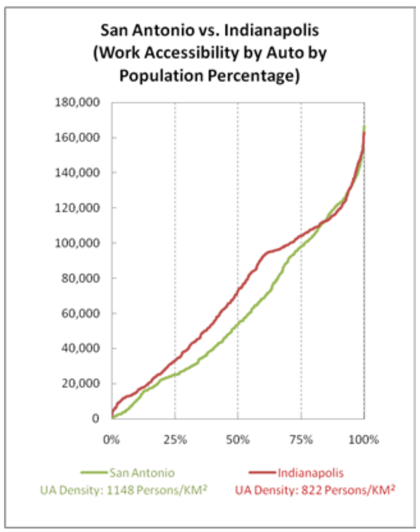

Kansas City vs. Charlotte
(Work Accessibility by Transit by
Population Percentage)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Kansas City
Charlotte
UA Density: 837 Persons/KM²
UA Density: 555 Persons/KM²

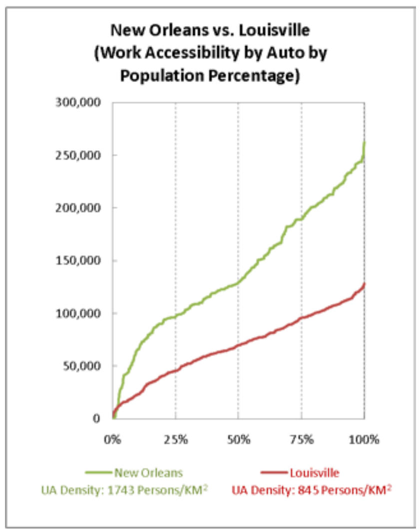

Las Vegas vs. Columbus
(Work Accessibility by Auto by
Population Percentage)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Las Vegas
UA Density: 1731 Persons/KM²
Columbus
UA Density: 1028Persons/KM²

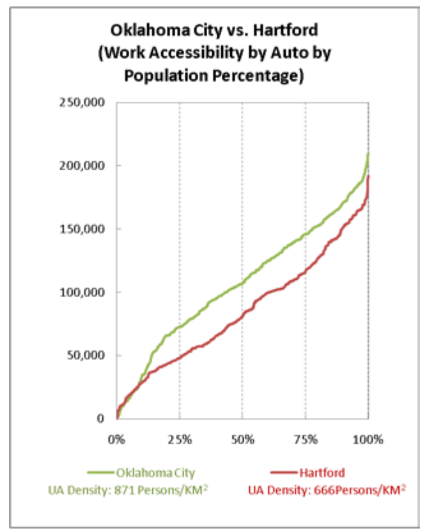

Las Vegas vs. Columbus
(Work Accessibility by Transit by
Population Percentage)
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Las Vegas
UA Density: 1731 Persons/KM²
Columbus
UA Density: 1028Persons/KM²

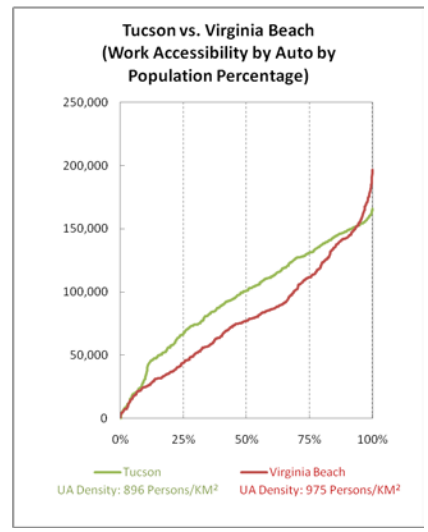

Memphis vs. Richmond
(Work Accessibility by Auto by
Population Percentage)
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
Memphis
UA Density: 940 Persons/KM²
Richmond
UA Density: 719 Persons/KM²


Memphis vs. Richmond
(Work Accessibility by Transit by
Population Percentage)
30,000
25,000
20,000
15,000
10,000
5,000
0
0%
25%
50%
75%
100%
Memphis
UA Density: 940 Persons/KM²
Richmond
UA Density: 719 Persons/KM²


San Antonio vs. Indianapolis
(Work Accessibility by Auto by
Population Percentage)
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0%
25%
50%
75%
100%
San Antonio
UA Density: 1148 Persons/KM²
Indianapolis
UA Density: 822 Persons/KM²

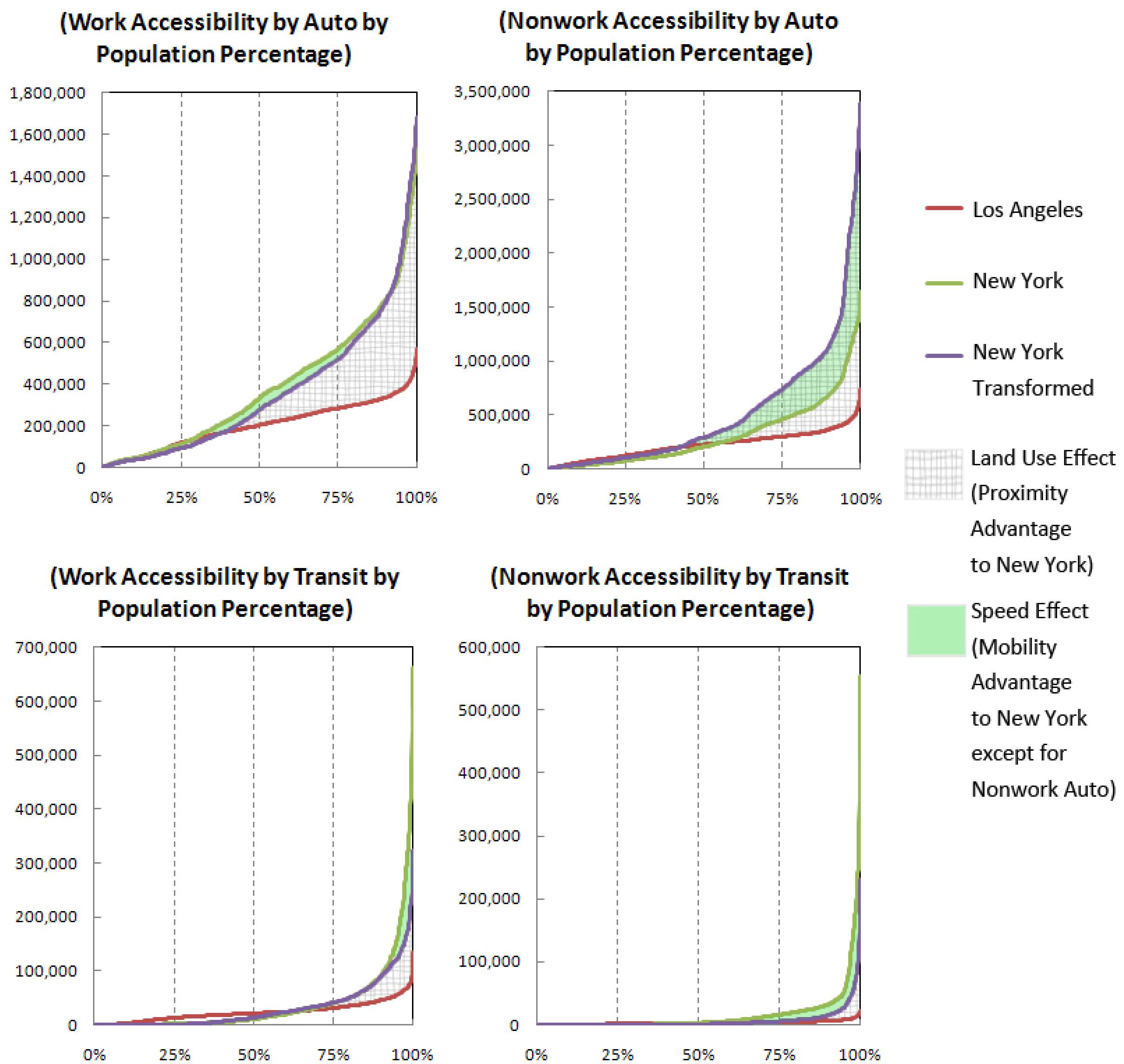

New Orleans vs. Louisville
(Work Accessibility by Auto by
Population Percentage)
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
New Orleans
UA Density: 1743 Persons/KM²
Louisville
UA Density: 845 Persons/KM²


Oklahoma City vs. Hartford
(Work Accessibility by Auto by
Population Percentage)
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Oklahoma City
UA Density: 871 Persons/KM²
Hartford
UA Density: 666Persons/KM²

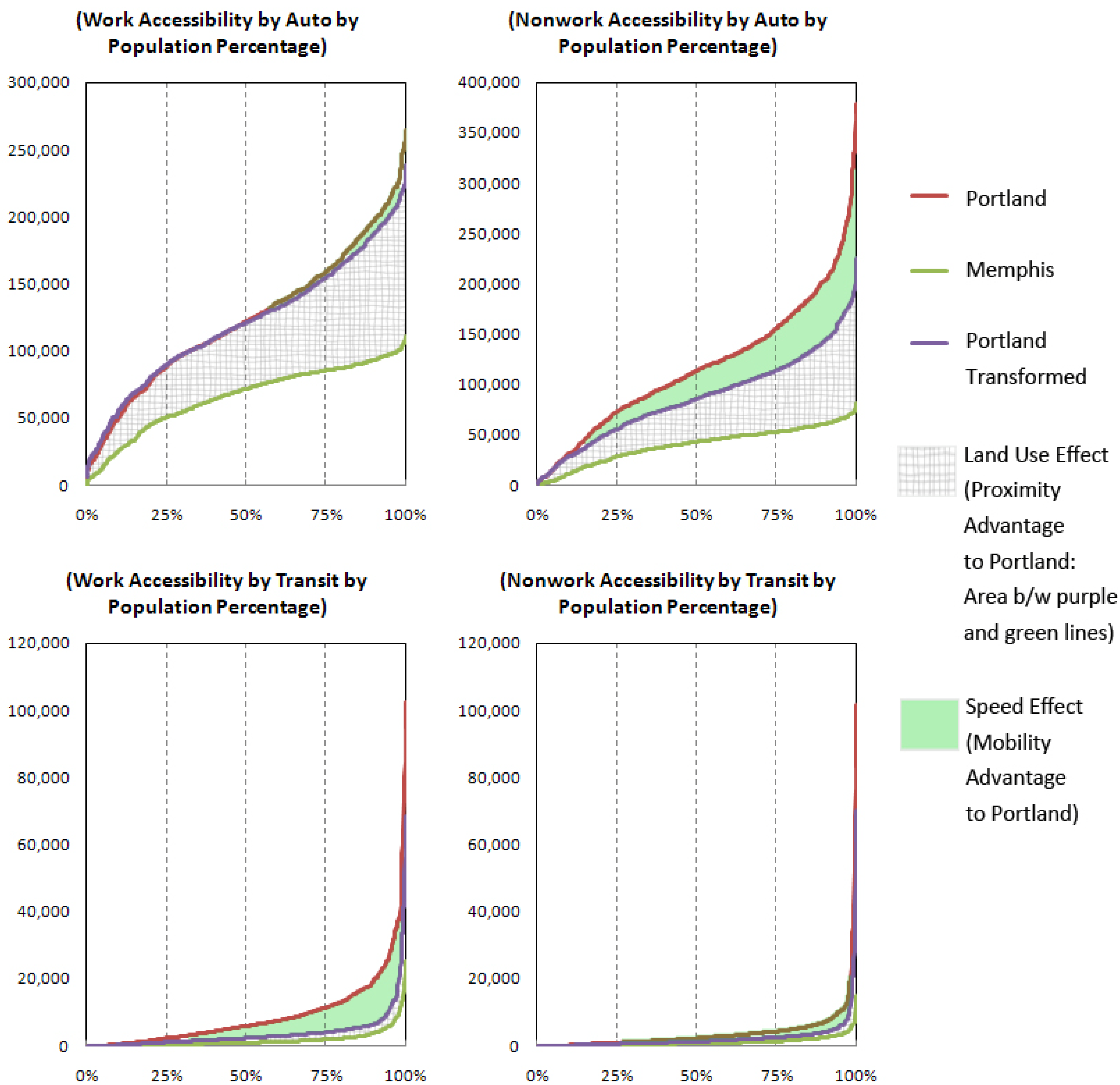

Tucson vs. Virginia Beach
(Work Accessibility by Auto by
Population Percentage)
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Tucson
UA Density: 896 Persons/KM²
Virginia Beach
UA Density: 975 Persons/KM²

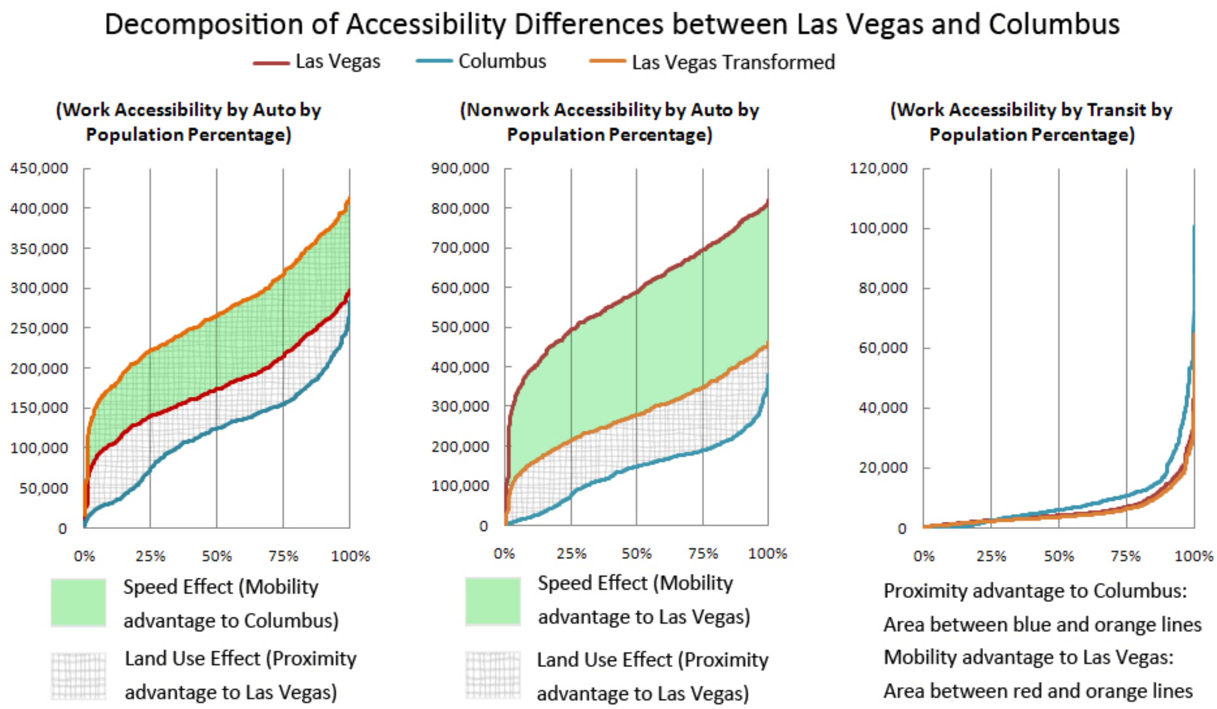
Appendix B: Decomposed Work-Auto Accessibility Differences for Selected Metropolitan Pairs

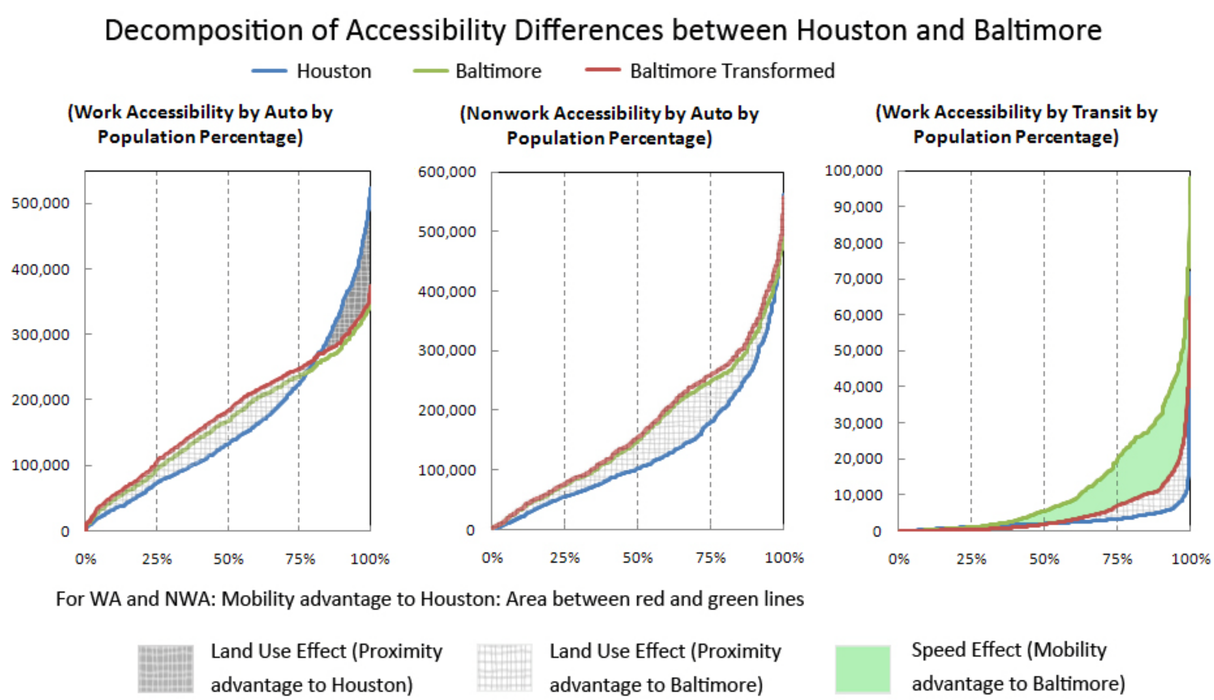
Decomposition of Accessibility Differences between New York and Los Angeles

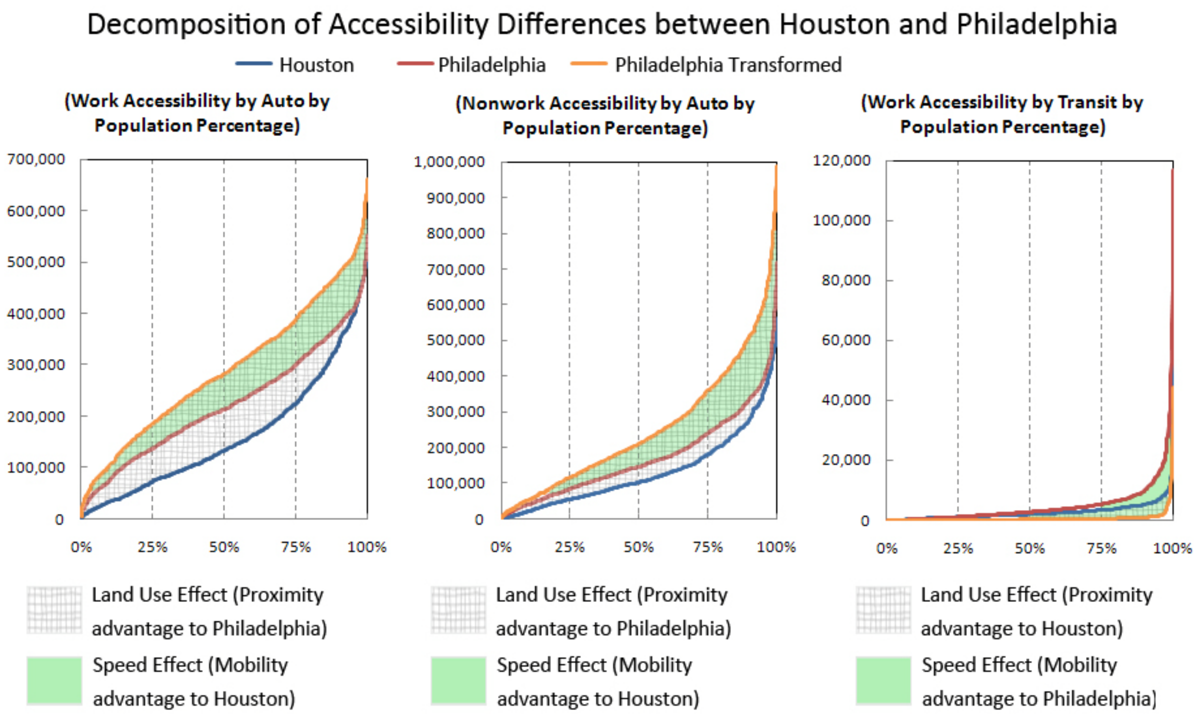


Decomposition of Accessibility Differences between Portland and Memphis



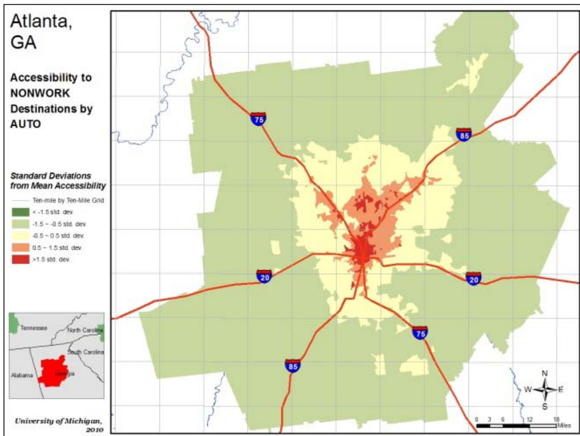

Decomposition of Accessibility Differences between Las Vegas and Columbus
Las Vegas
Columbus
Las Vegas Transformed
(Work Accessibility by Auto by Population Percentage)
(Nonwork Accessibility by Auto by Population Percentage)
(Work Accessibility by Transit by Population Percentage)
Speed Effect (Mobility advantage to Columbus)
Land Use Effect (Proximity advantage to Las Vegas)
Speed Effect (Mobility advantage to Las Vegas)
Land Use Effect (Proximity advantage to Las Vegas)
Proximity advantage to Columbus: Area between blue and orange lines
Mobility advantage to Las Vegas: Area between red and orange lines

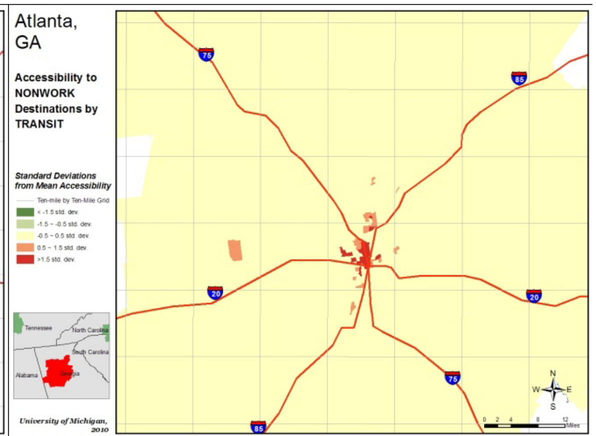

Decomposition of Accessibility Differences between Houston and Baltimore
Houston
Baltimore
Baltimore Transformed
(Work Accessibility by Auto by Population Percentage)
(Nonwork Accessibility by Auto by Population Percentage)
(Work Accessibility by Transit by Population Percentage)
For WA and NWA: Mobility advantage to Houston: Area between red and green lines
Land Use Effect (Proximity advantage to Houston)
Land Use Effect (Proximity advantage to Baltimore)
Speed Effect (Mobility advantage to Baltimore)

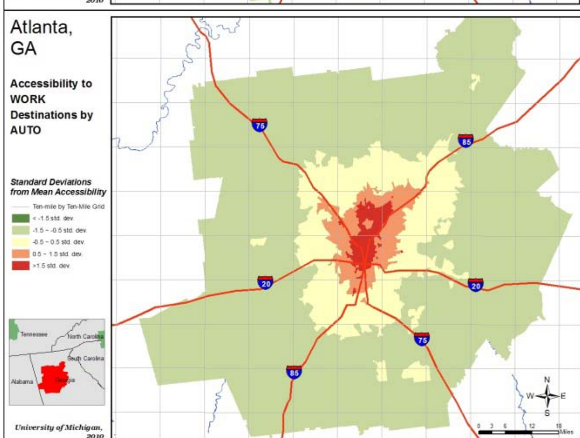


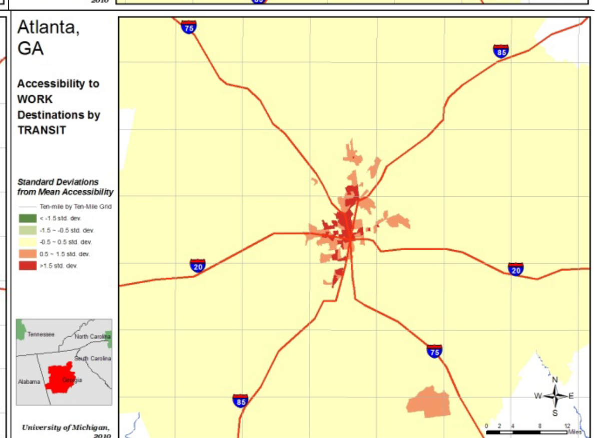
Decomposition of Accessibility Differences between Houston and Philadelphia
Houston
Philadelphia
Philadelphia Transformed
(Work Accessibility by Auto by Population Percentage)
(Nonwork Accessibility by Auto by Population Percentage)
(Work Accessibility by Transit by Population Percentage)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
120,000
100,000
80,000
60,000
40,000
20,000
0%
25%
50%
75%
100%
Land Use Effect (Proximity advantage to Philadelphia)
Speed Effect (Mobility advantage to Houston)
Land Use Effect (Proximity advantage to Philadelphia)
Speed Effect (Mobility advantage to Houston)
Land Use Effect (Proximity advantage to Houston)
Speed Effect (Mobility advantage to Philadelphia)

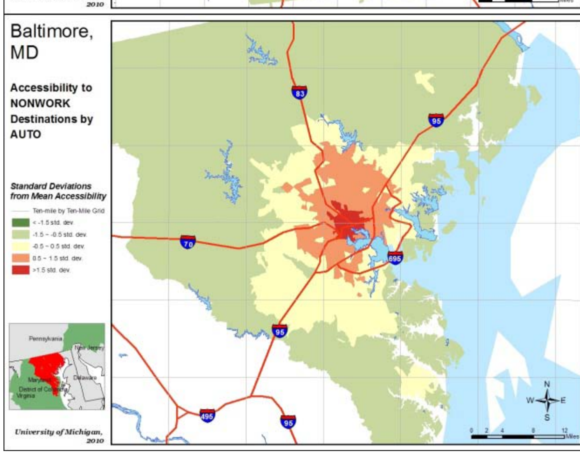
Appendix C: Accessibility Maps: Work, Non-Work, Auto, Transit

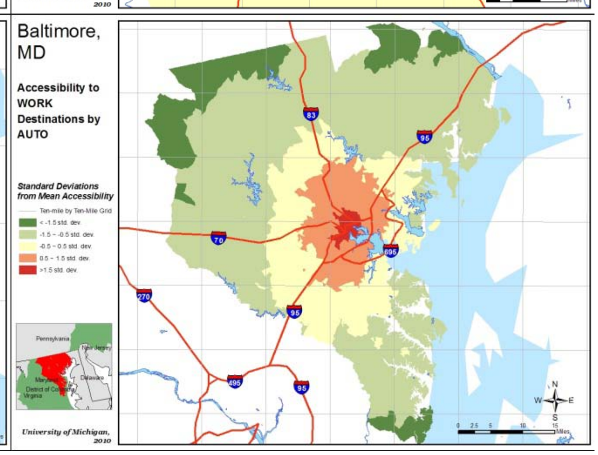


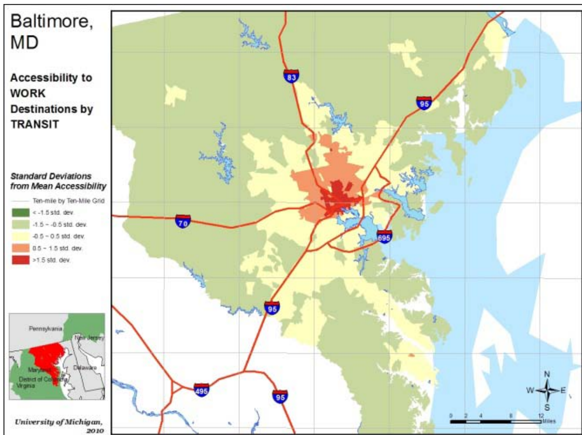


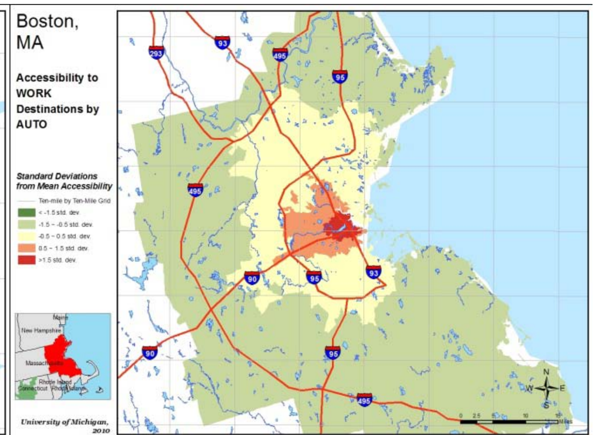


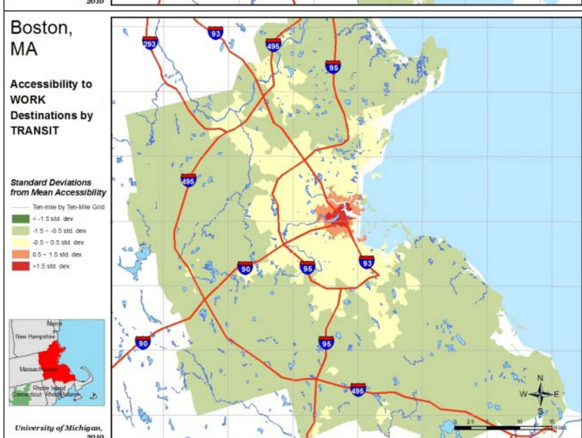


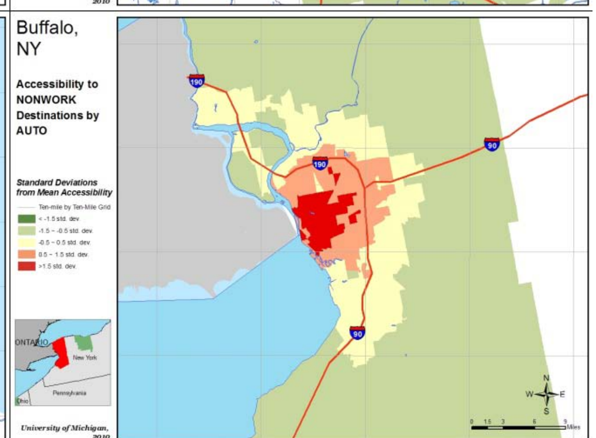


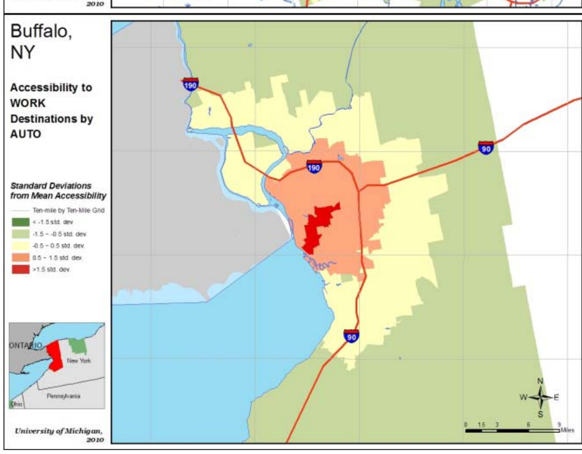


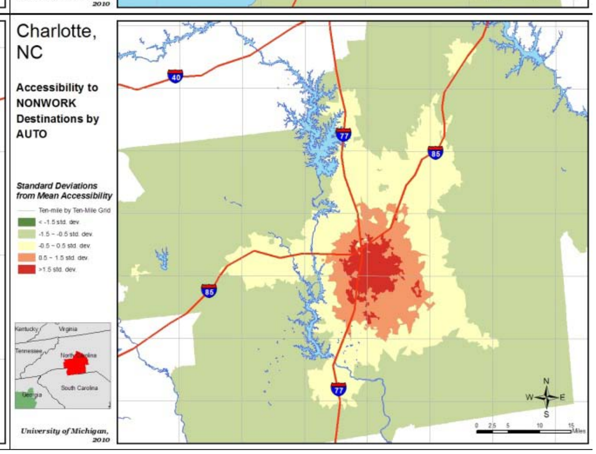

Baltimore, MD
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

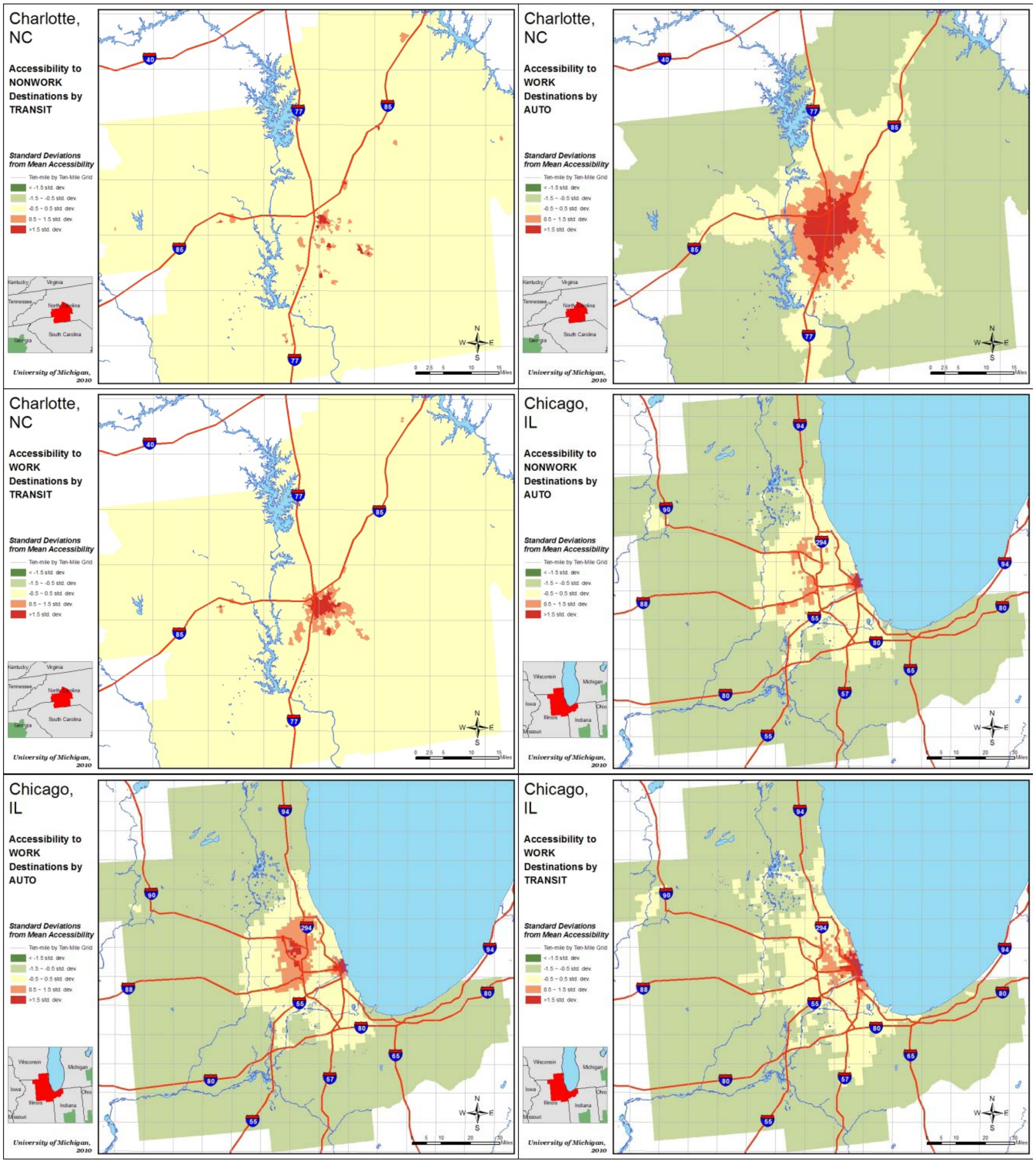

Boston, MA
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

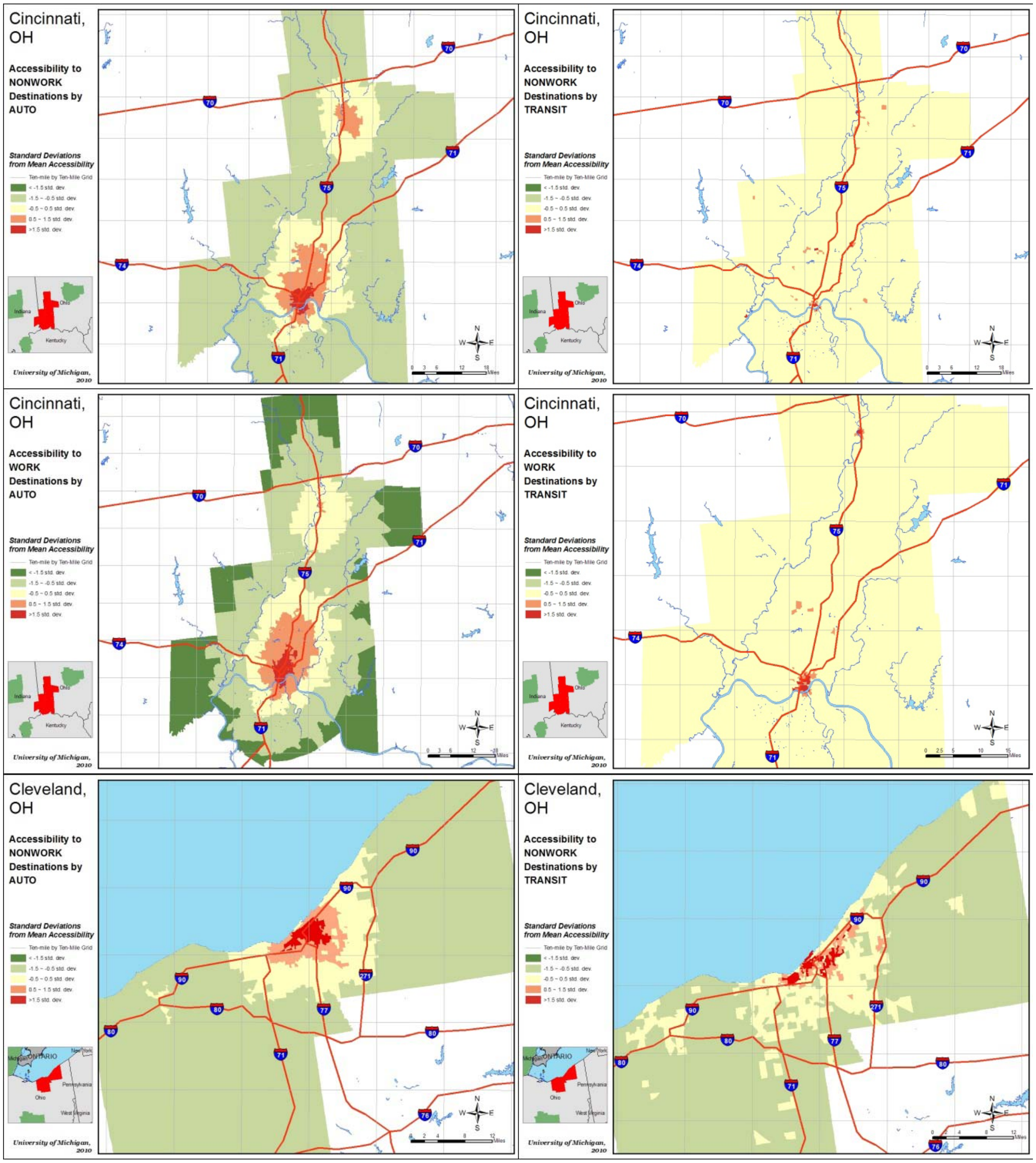

Boston, MA
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010


Buffalo, NY
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

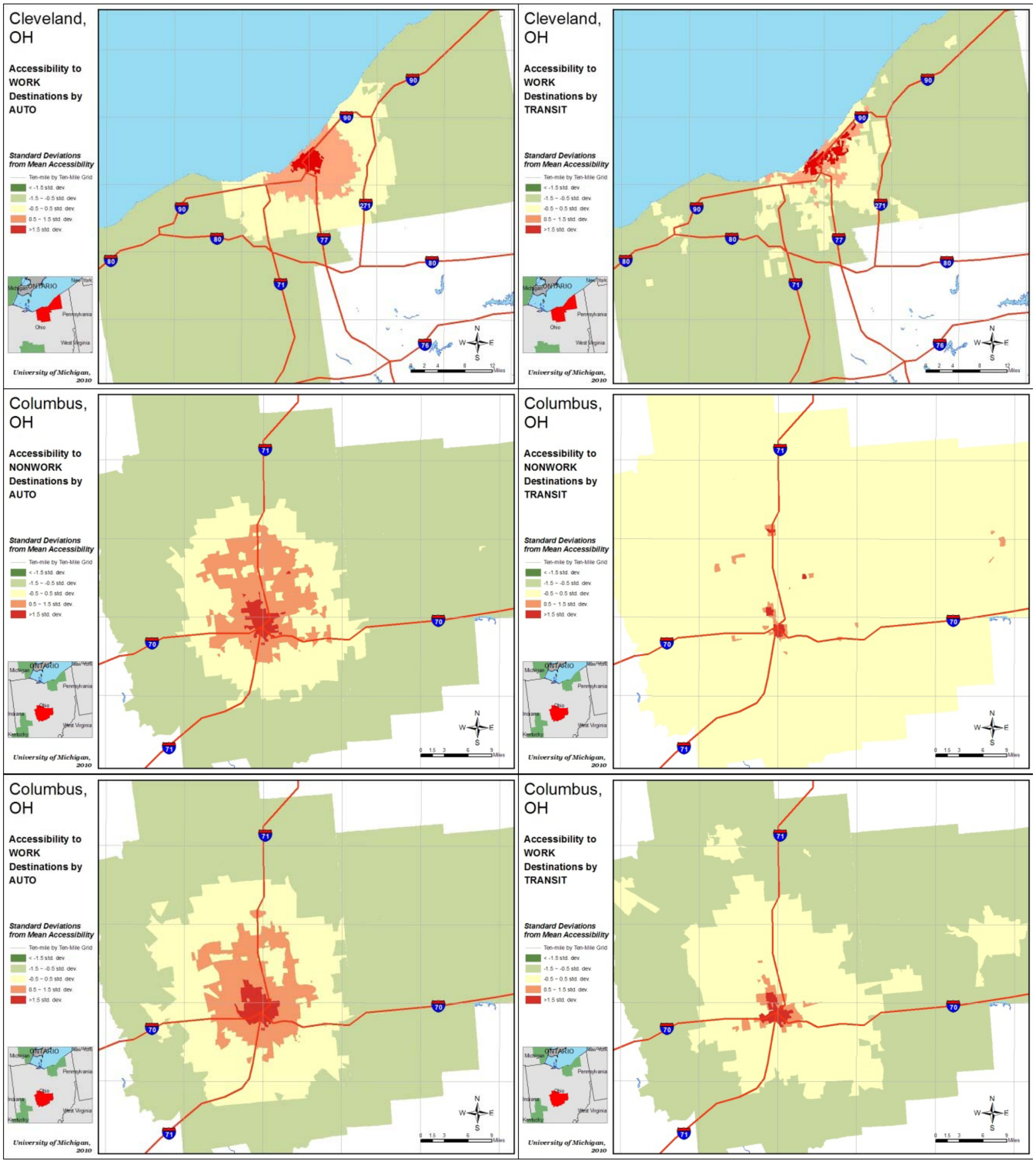

Buffalo, NY
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

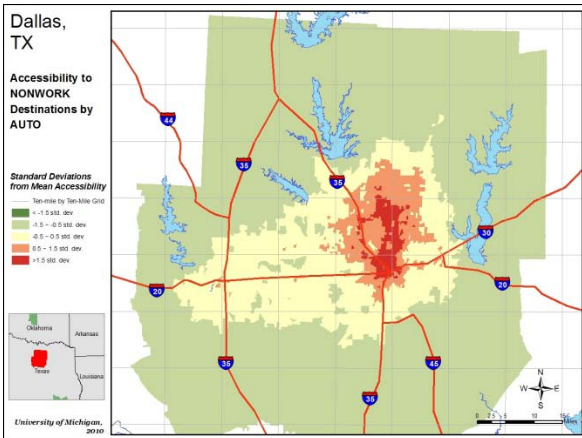

Charlotte, NC
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010


Charlotte, NC
Accessibility to NONWORK Destinations by TRANSIT
Charlotte, NC
Accessibility to WORK Destinations by AUTO
Charlotte, NC
Accessibility to WORK Destinations by TRANSIT
Chicago, IL
Accessibility to NONWORK Destinations by AUTO
Chicago, IL
Accessibility to WORK Destinations by AUTO
Chicago, IL
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

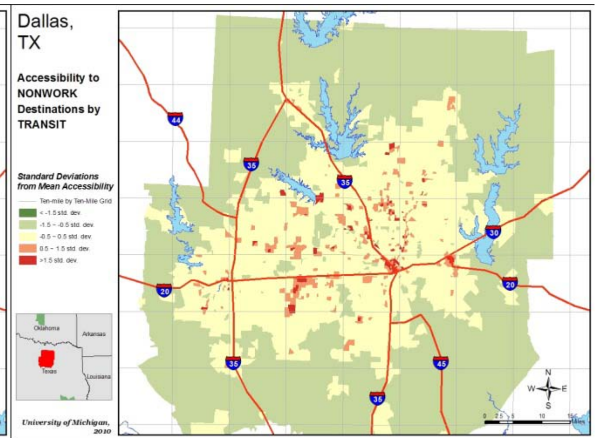


Cincinnati, OH
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010
Cincinnati, OH
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Cincinnati, OH
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Cincinnati, OH
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Cleveland, OH
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Cleveland, OH
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010

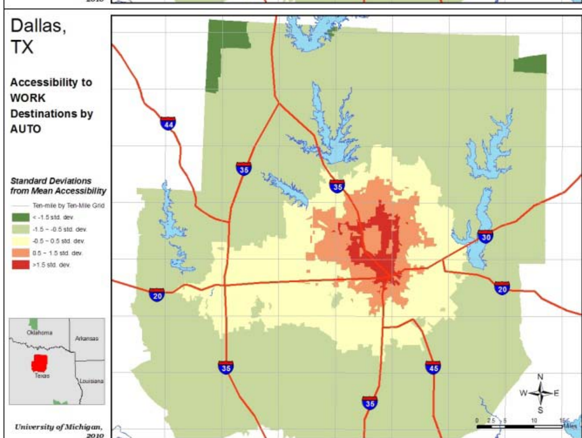

Cleveland, OH
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010
Cleveland, OH
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Columbus, OH
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Columbus, OH
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Columbus, OH
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Columbus, OH
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010



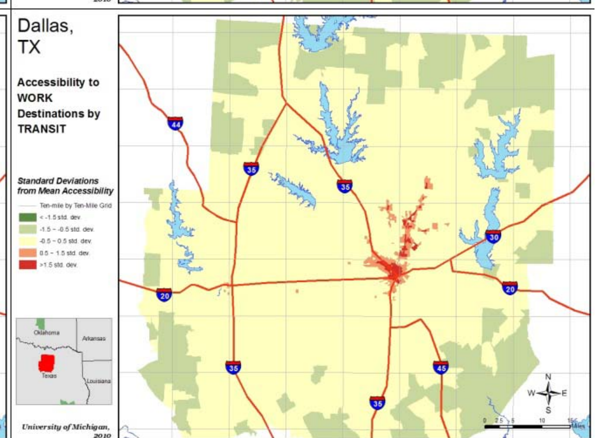
Dallas, TX
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010



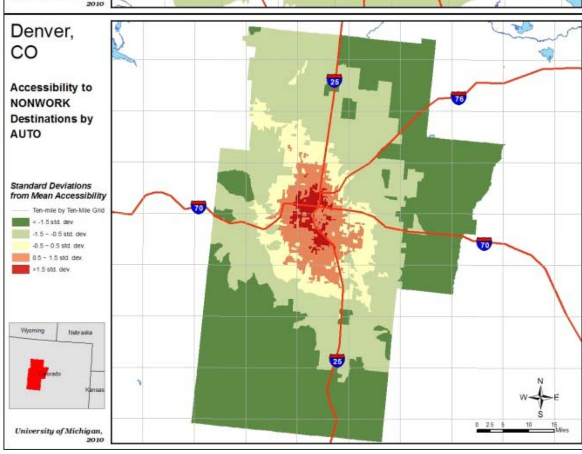
Dallas, TX
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010



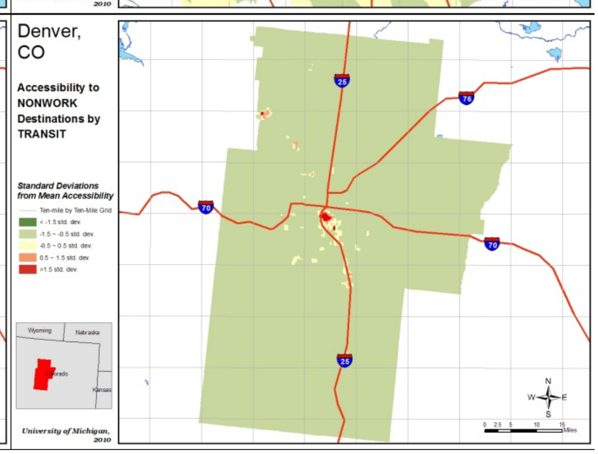
Dallas, TX
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010



Dallas, TX
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

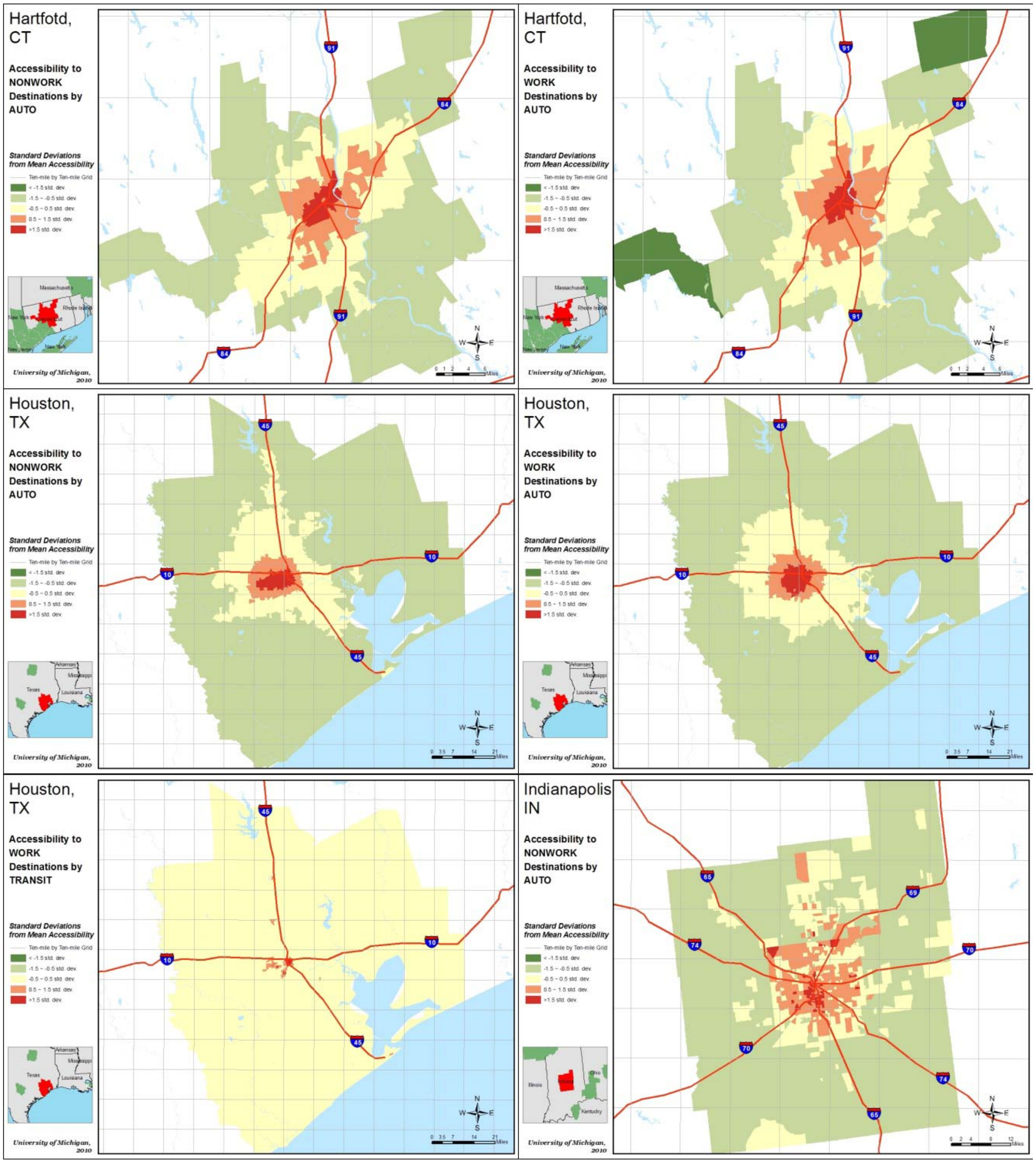


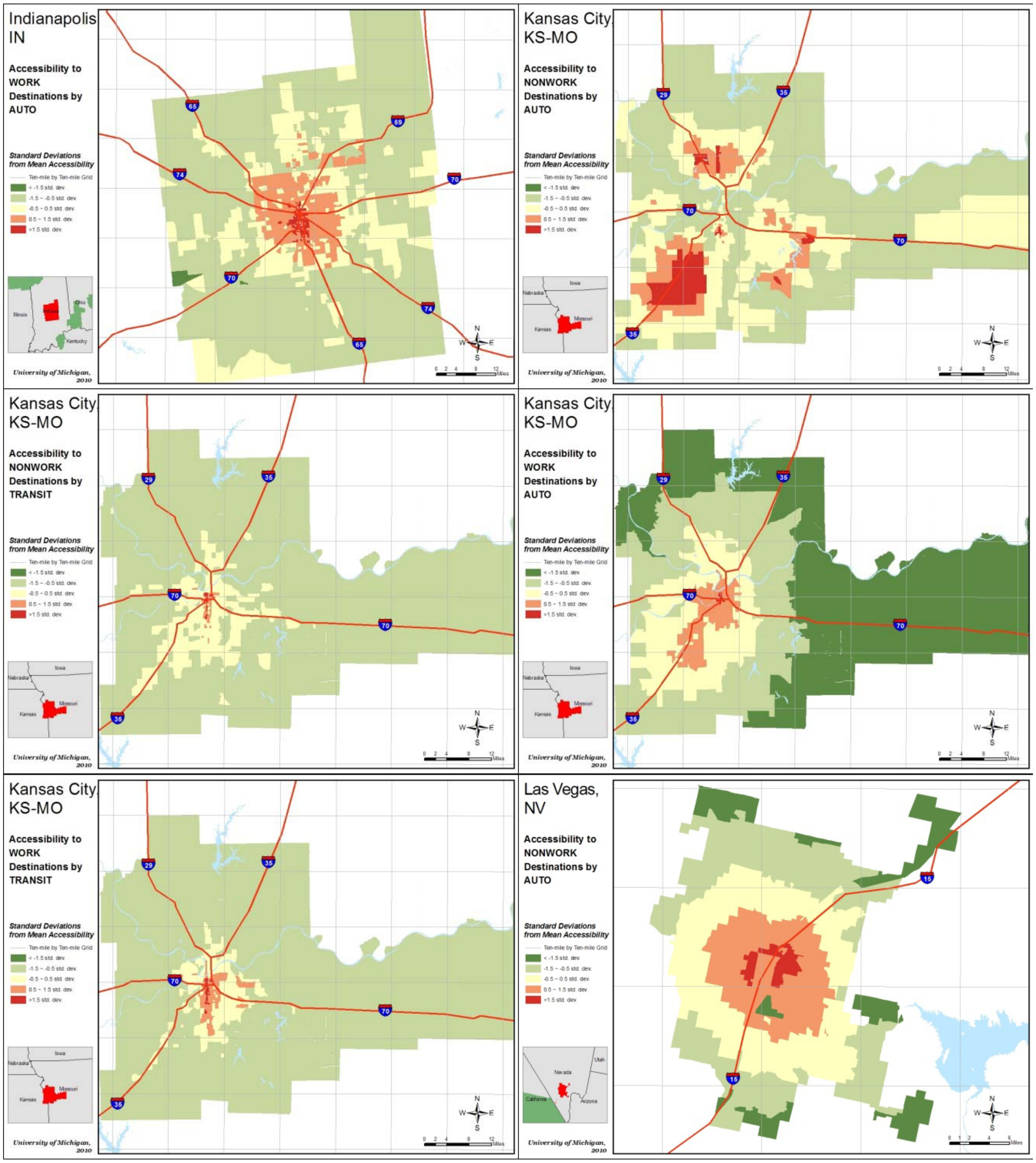
Denver, CO
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010



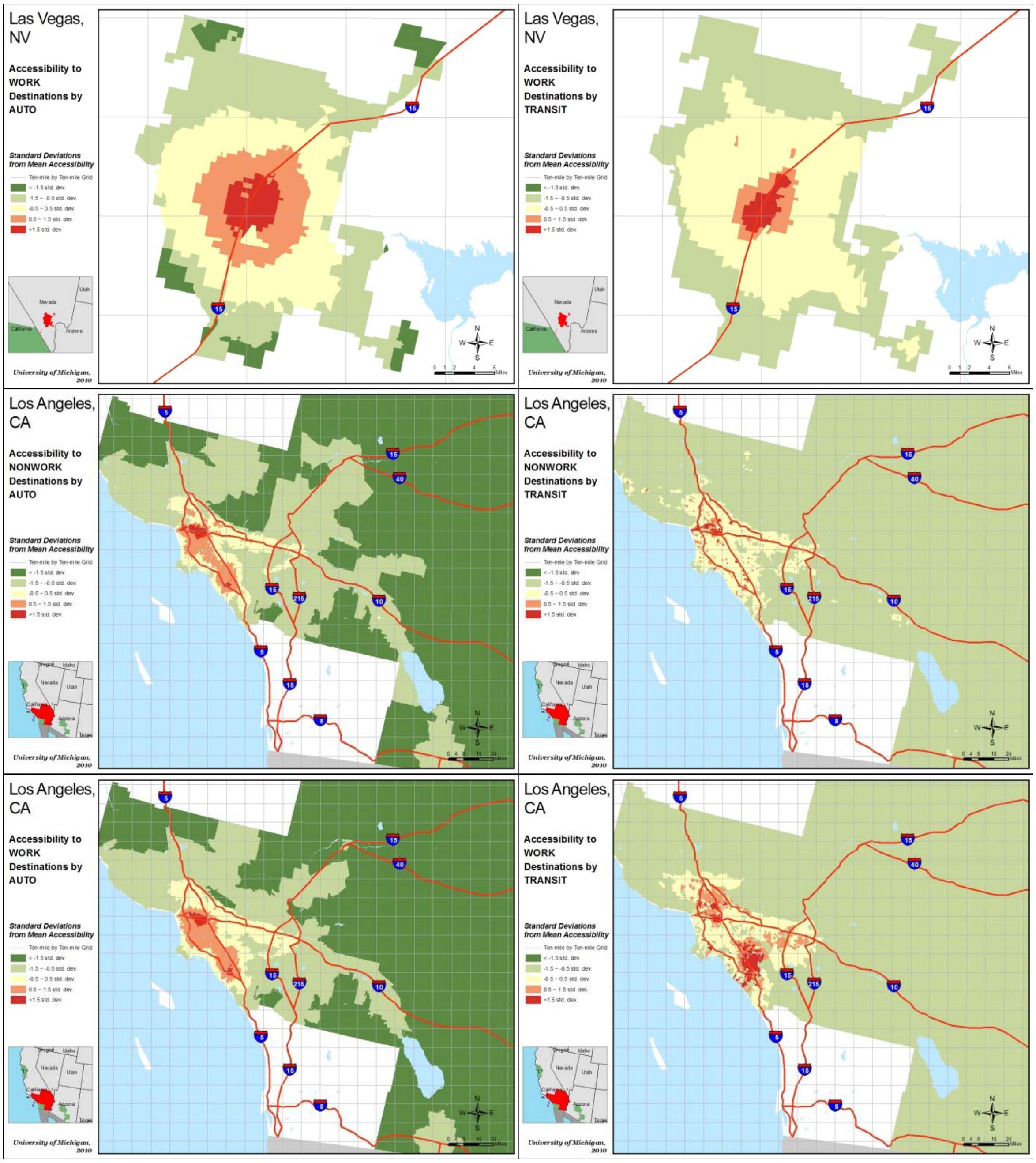
Denver, CO
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

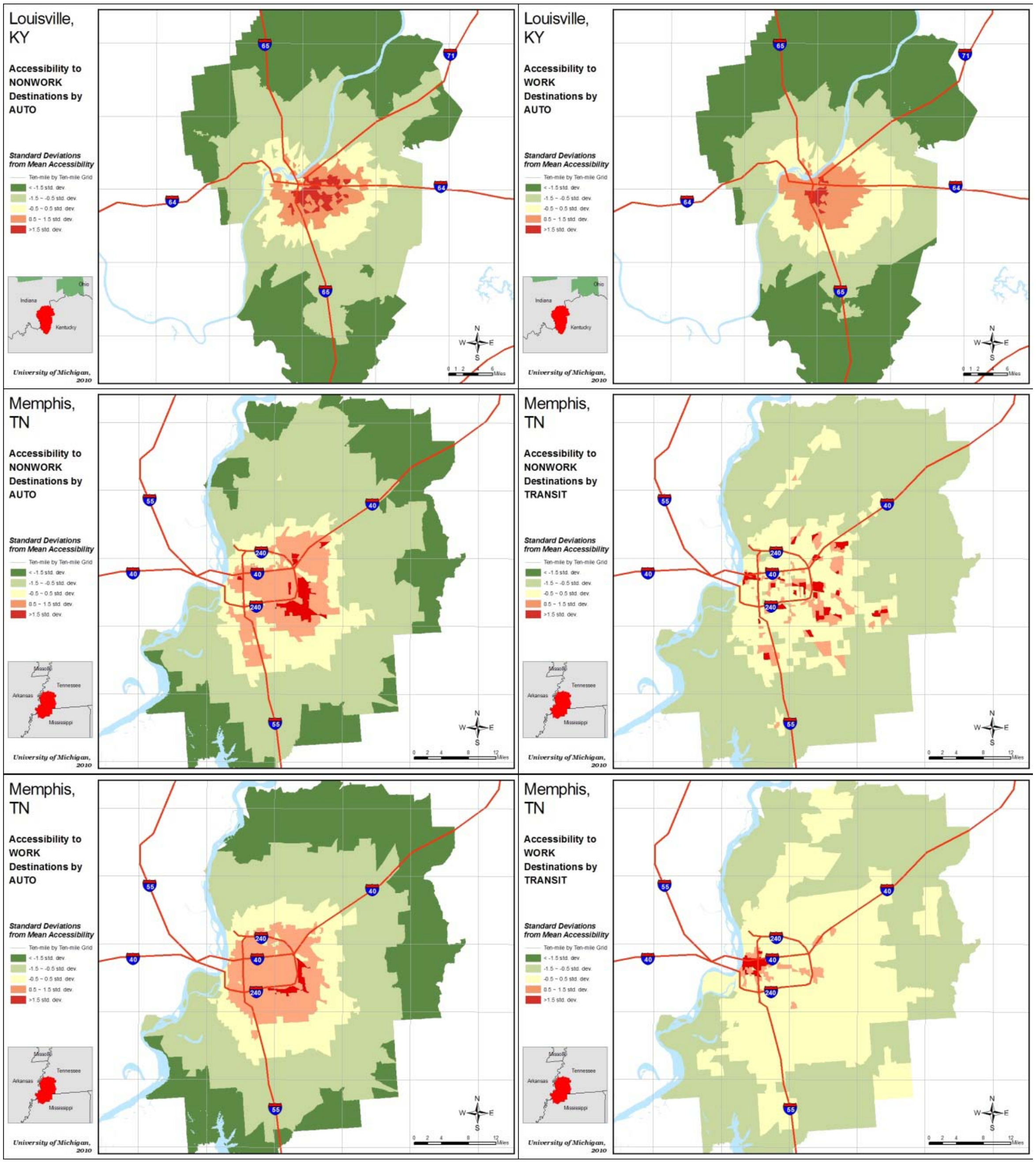

Denver, CO
Accessibility to WORK Destinations by AUTO
Denver, CO
Accessibility to WORK Destinations by TRANSIT
Detroit, MI
Accessibility to NONWORK Destinations by AUTO
Detroit, MI
Accessibility to NONWORK Destinations by TRANSIT
Detroit, MI
Accessibility to WORK Destinations by AUTO
Detroit, MI
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-Mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010

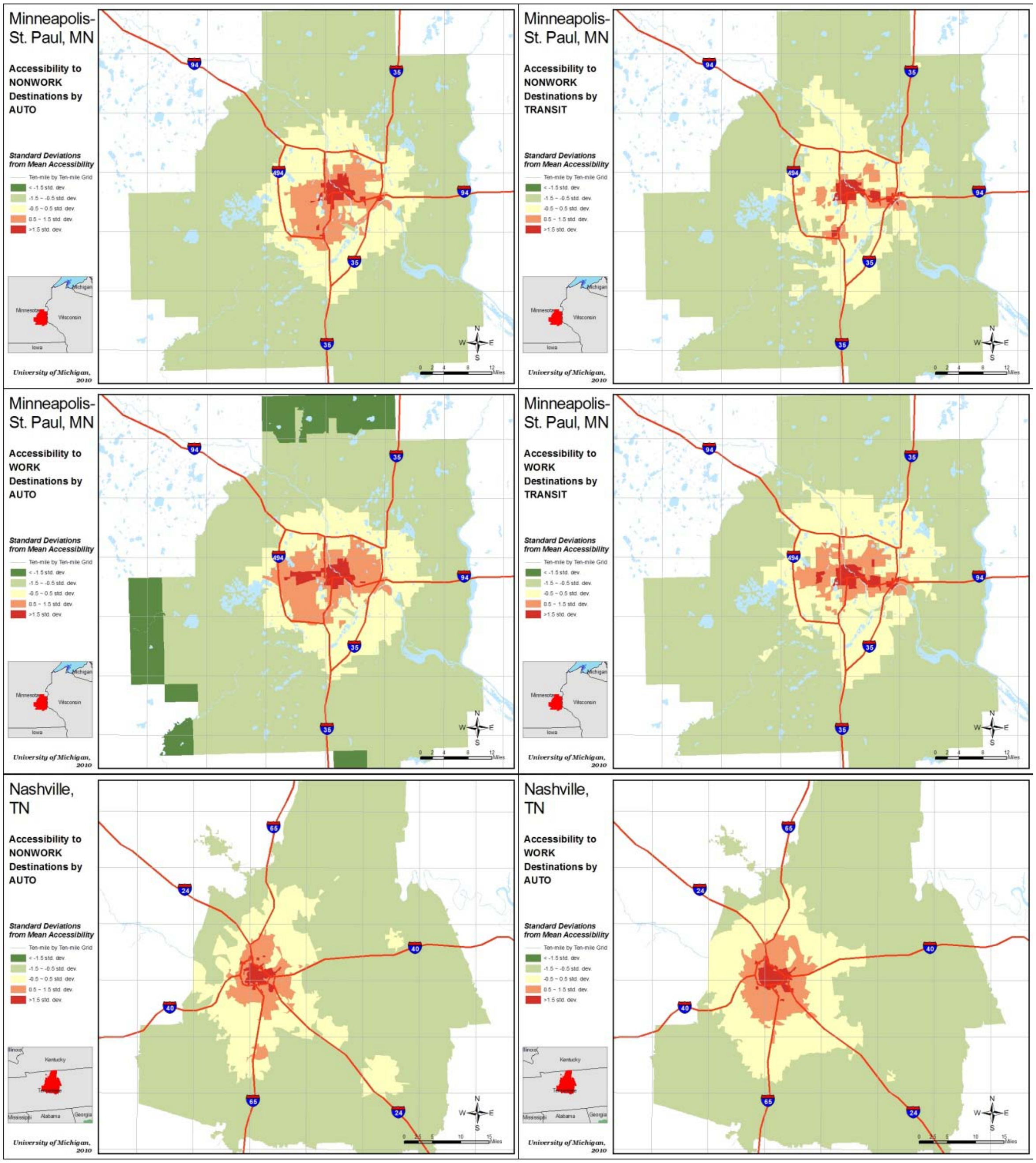

Hartfotd, CT
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Hartfotd, CT
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Houston, TX
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Houston, TX
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Houston, TX
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
University of Michigan, 2010
Indianapolis IN
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010



Indianapolis IN
Accessibility to WORK Destinations by AUTO
Kansas City, KS-MO
Accessibility to NONWORK Destinations by AUTO
Kansas City, KS-MO
Accessibility to NONWORK Destinations by TRANSIT
Kansas City, KS-MO
Accessibility to WORK Destinations by AUTO
Kansas City, KS-MO
Accessibility to WORK Destinations by TRANSIT
Las Vegas, NV
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010


Las Vegas, NV
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev
-1.5 ~ -0.5 std. dev
-0.5 ~ 0.5 std. dev
0.5 ~ 1.5 std. dev
>1.5 std. dev
University of Michigan, 2010
Las Vegas, NV
Accessibility to WORK Destinations by TRANSIT
University of Michigan, 2010
Los Angeles, CA
Accessibility to NONWORK Destinations by AUTO
University of Michigan, 2010
Los Angeles, CA
Accessibility to NONWORK Destinations by TRANSIT
University of Michigan, 2010
Los Angeles, CA
Accessibility to WORK Destinations by AUTO
University of Michigan, 2010
Los Angeles, CA
Accessibility to WORK Destinations by TRANSIT
University of Michigan, 2010


Louisville, KY
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
Ohio
Indiana
Kentucky
University of Michigan, 2010
Louisville, KY
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
University of Michigan, 2010
Memphis, TN
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
University of Michigan, 2010
Memphis, TN
Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
University of Michigan, 2010
Memphis, TN
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
University of Michigan, 2010
Memphis, TN
Accessibility to WORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
Ten-mile by Ten-mile Grid
< -1.5 std. dev.
-1.5 ~ -0.5 std. dev.
-0.5 ~ 0.5 std. dev.
0.5 ~ 1.5 std. dev.
>1.5 std. dev.
University of Michigan, 2010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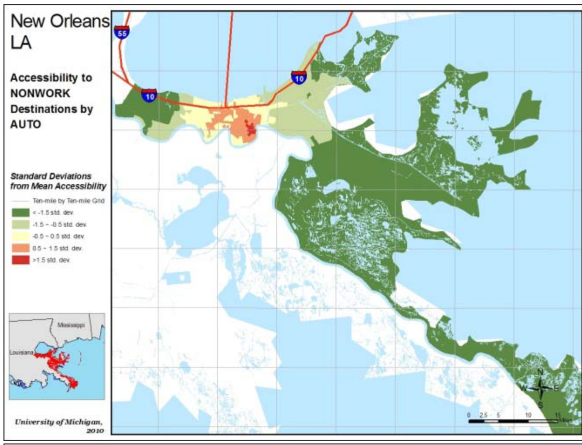
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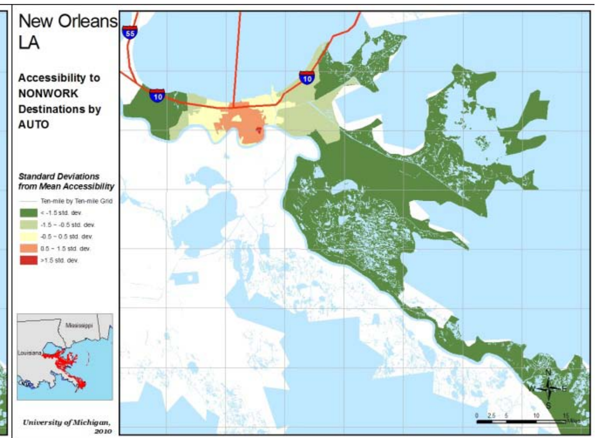
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Destinations by
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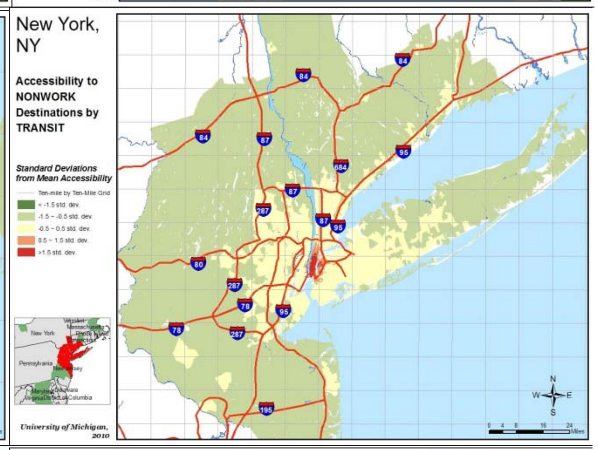
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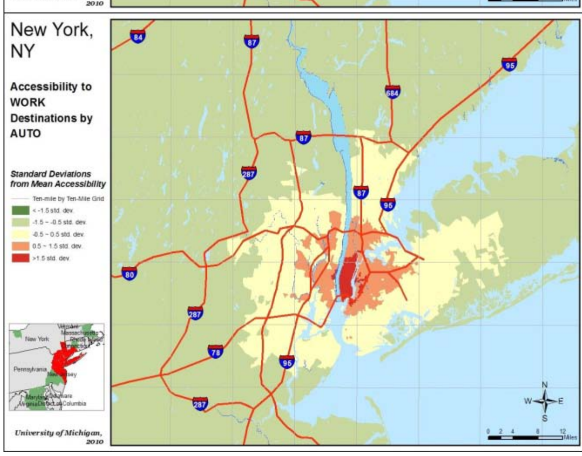
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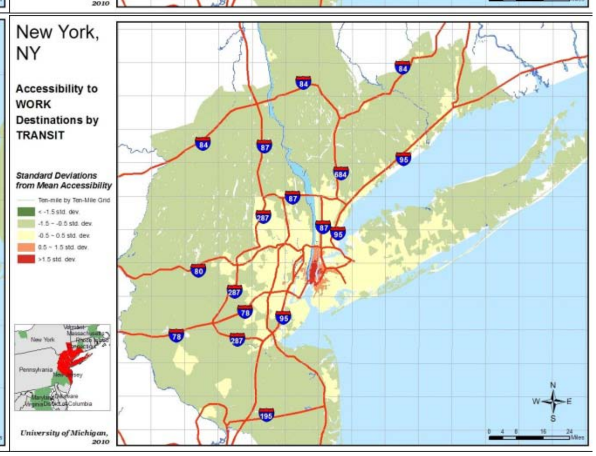
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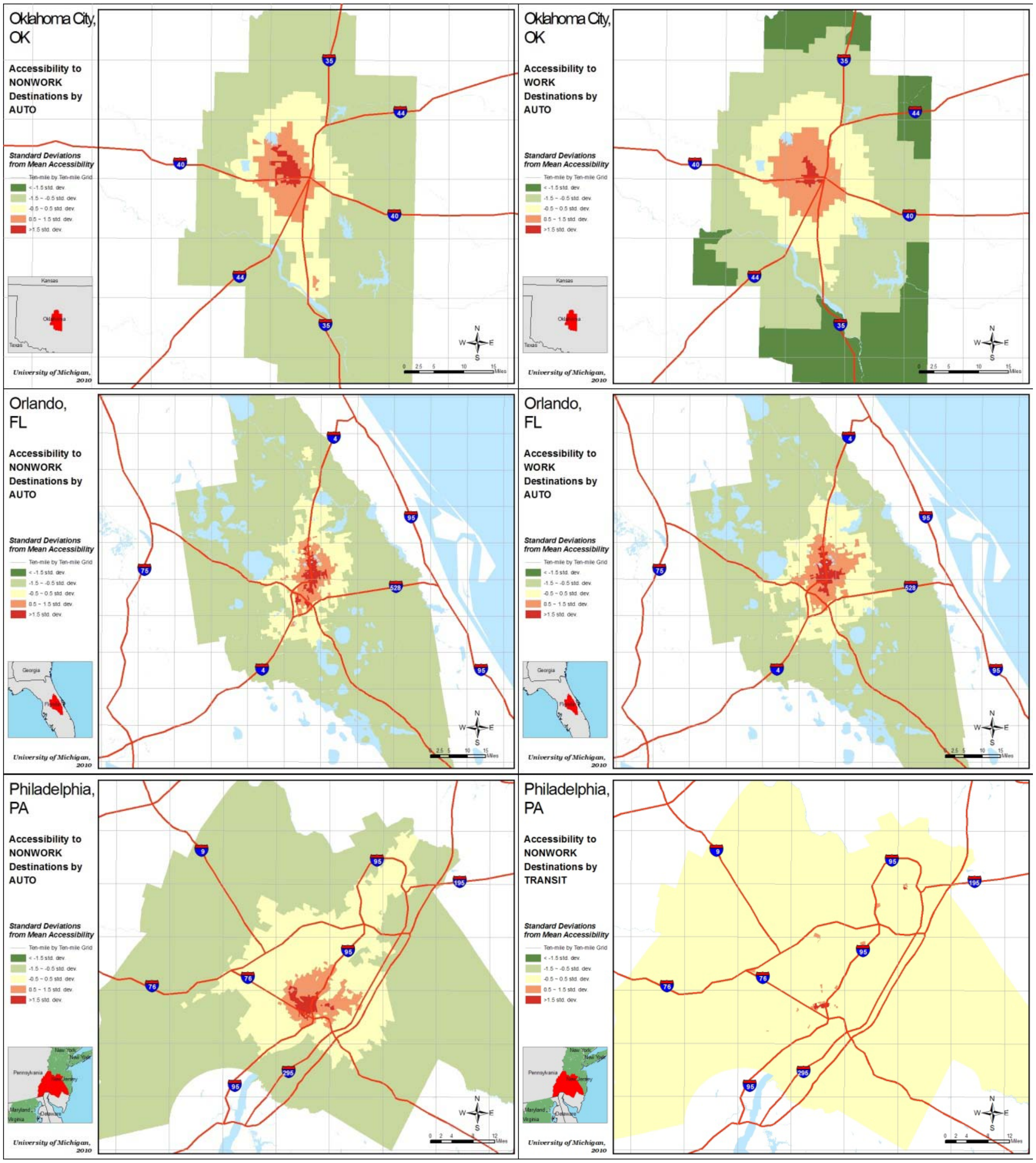
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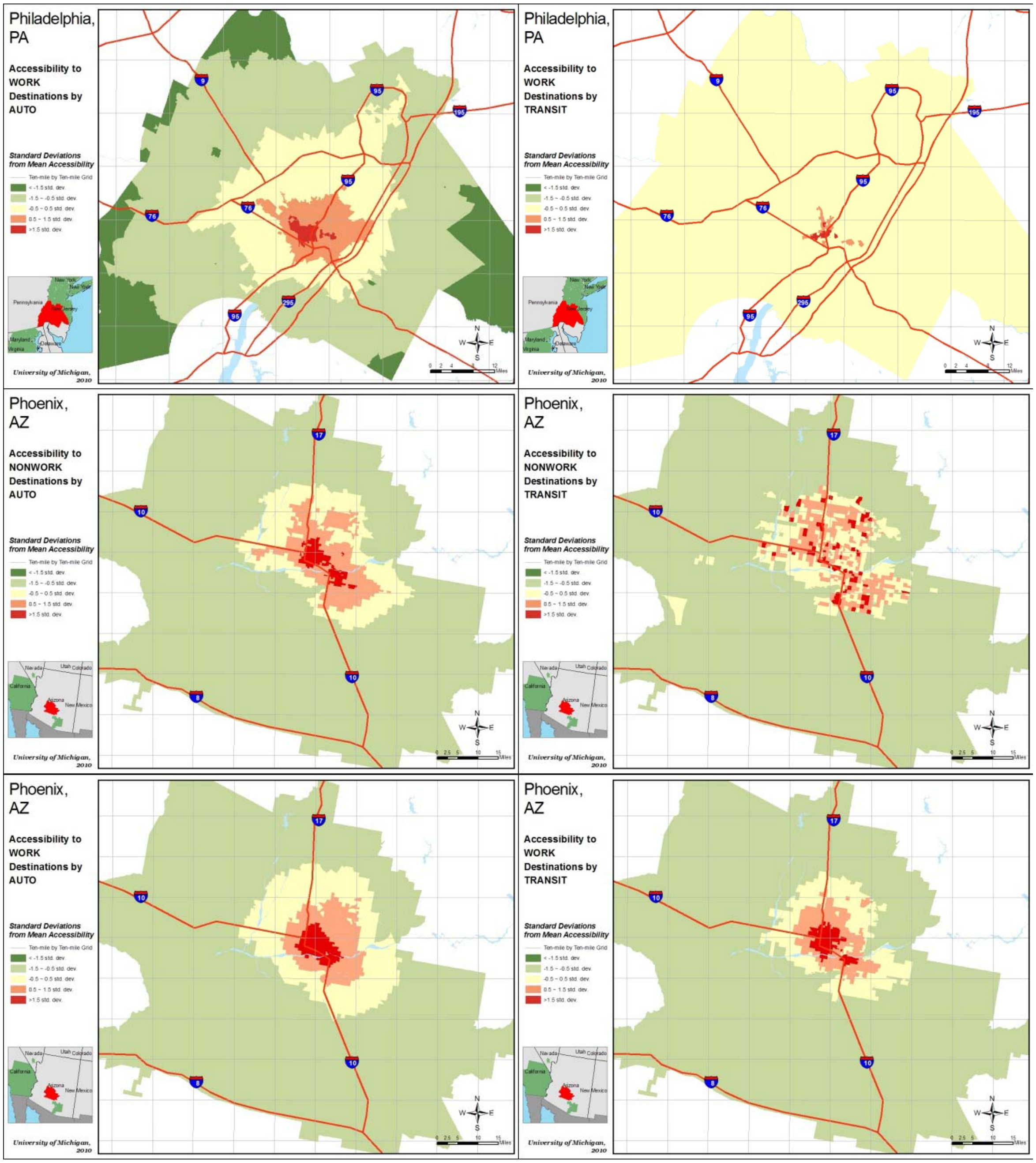
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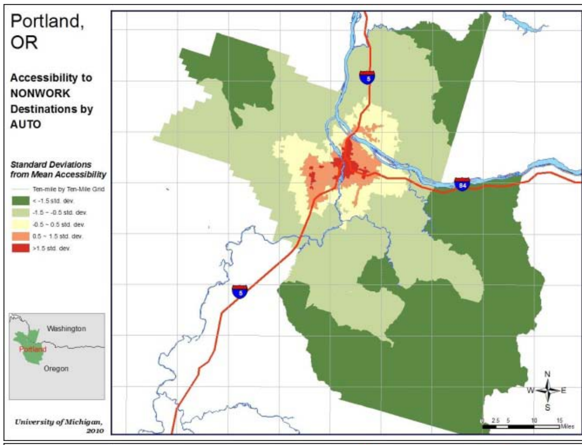
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University of Michigan, 2010
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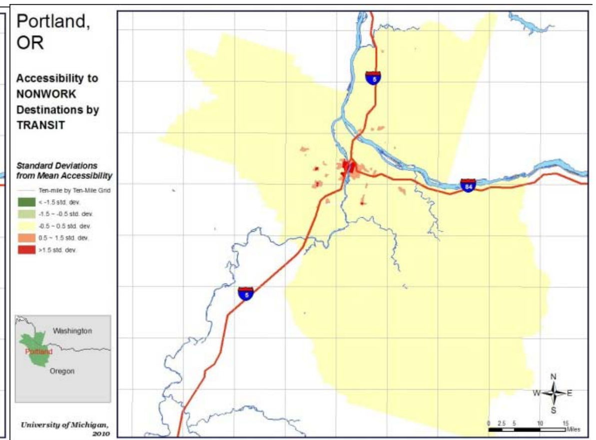
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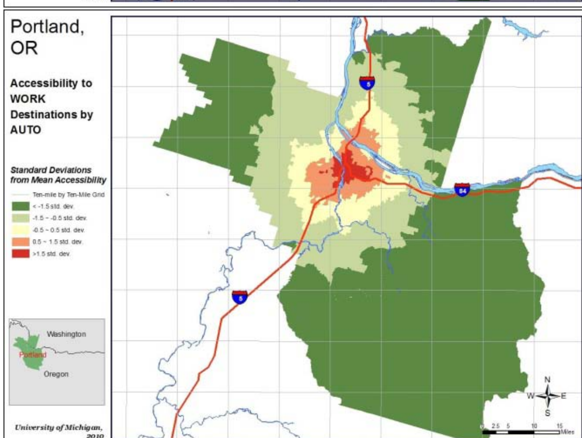
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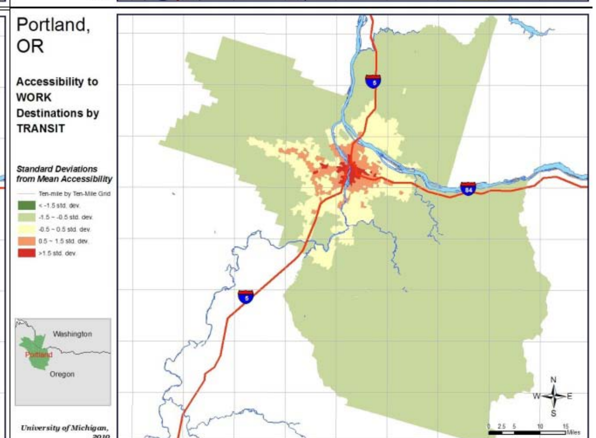
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University of Michigan, 2010
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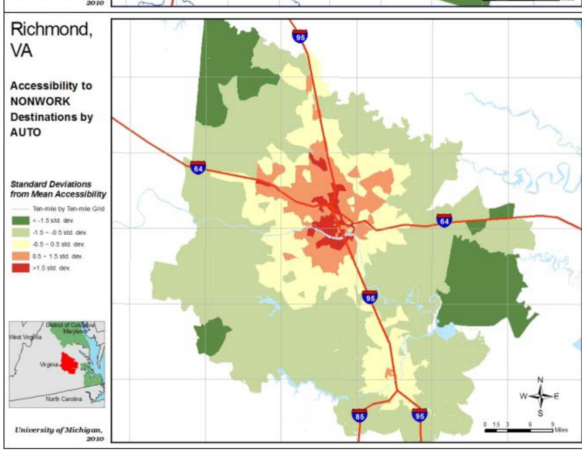
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>1.5 std. dev.
North Carolina
University of Michigan, 2010
95
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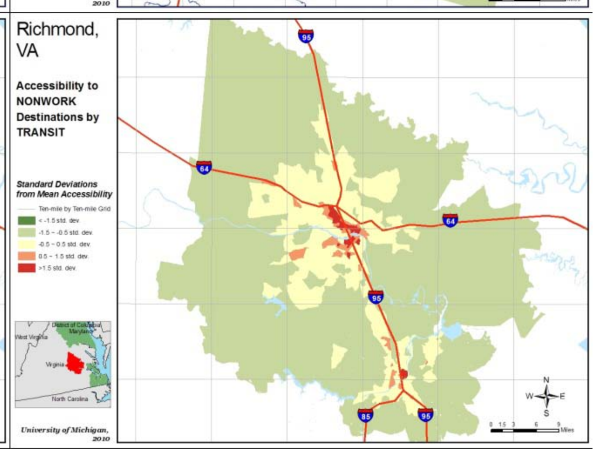
Miles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North Carolina
University of Michigan, 2010
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Richmond, VA
Accessibility to WORK Destinations by AUTO
Richmond, VA
Accessibility to WORK Destinations by TRANSIT
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Accessibility to WORK Destinations by AUTO
San Antonio, TX
Accessibility to NONWORK Destinations by AUTO
San Antonio, TX
Accessibility to WORK Destinations by AUTO
San Diego, CA
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
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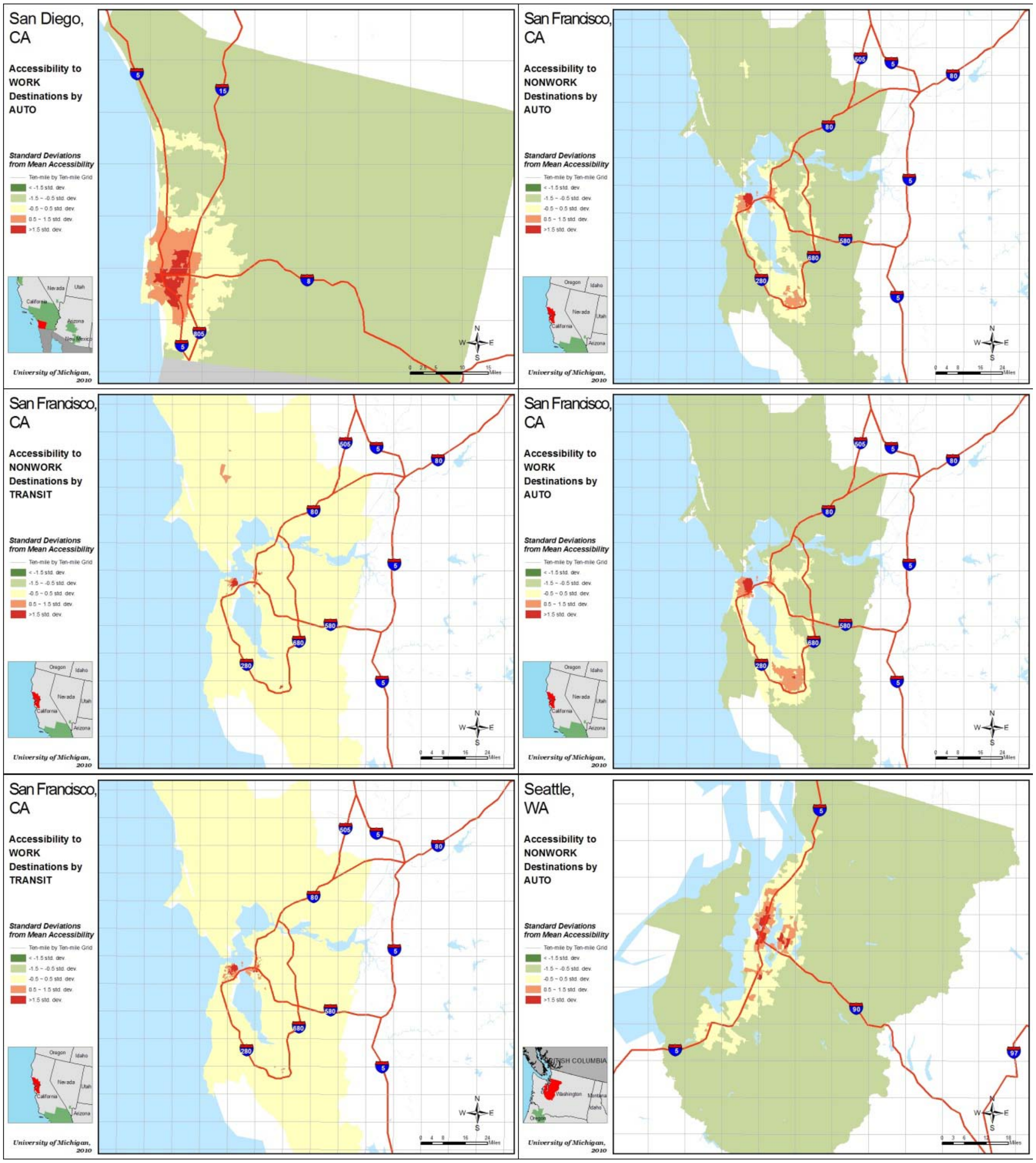
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>1.5 std. dev
University of Michigan, 2010
San Francisco, CA
Accessibility to NONWORK Destinations by AUTO
Standard Deviations from Mean Accessibility
University of Michigan, 2010
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Accessibility to NONWORK Destinations by TRANSIT
Standard Deviations from Mean Accessibility
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San Francisco, CA
Accessibility to WORK Destinations by AUTO
Standard Deviations from Mean Accessibility
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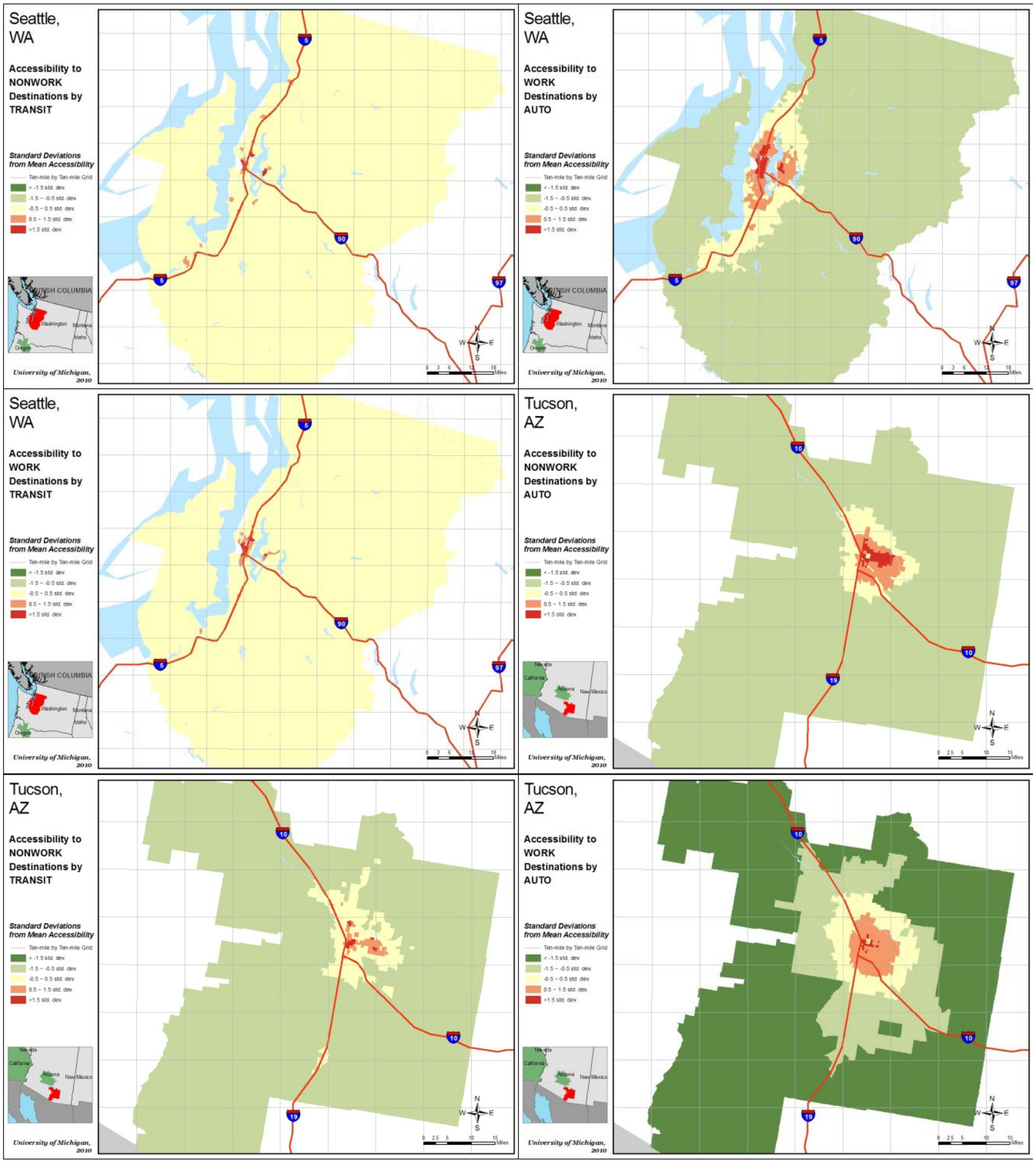
University of Michigan, 2010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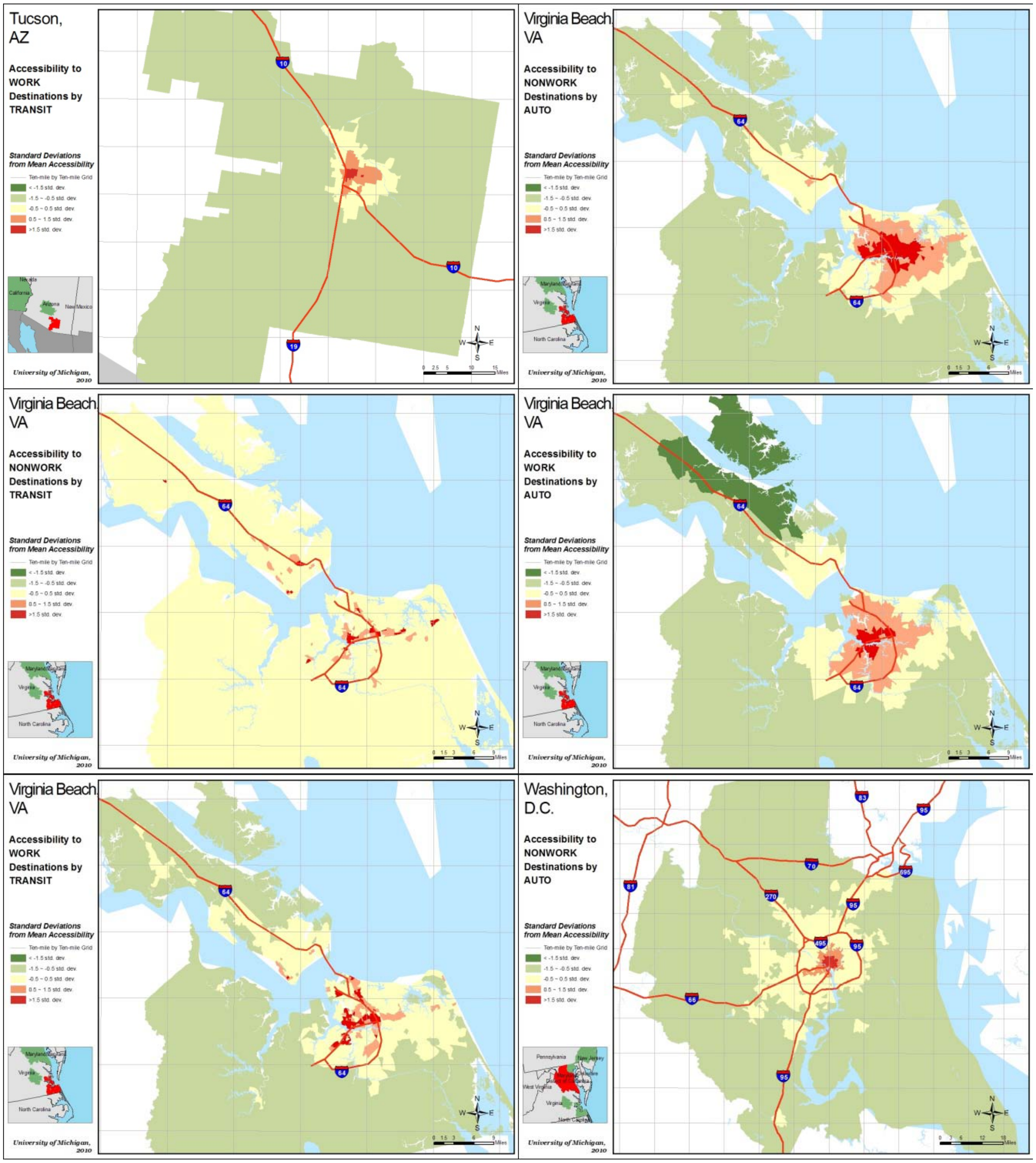
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Nevada
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10
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Virginia Beach, VA
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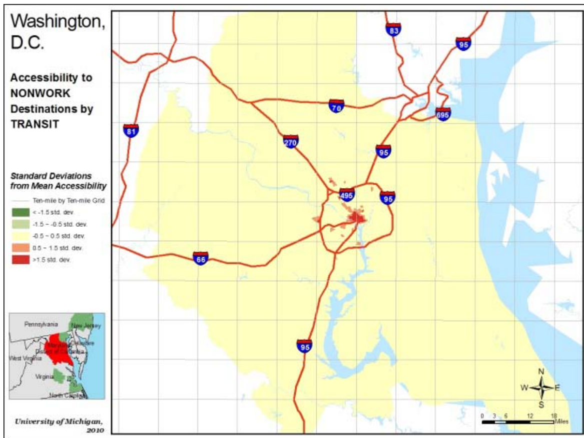
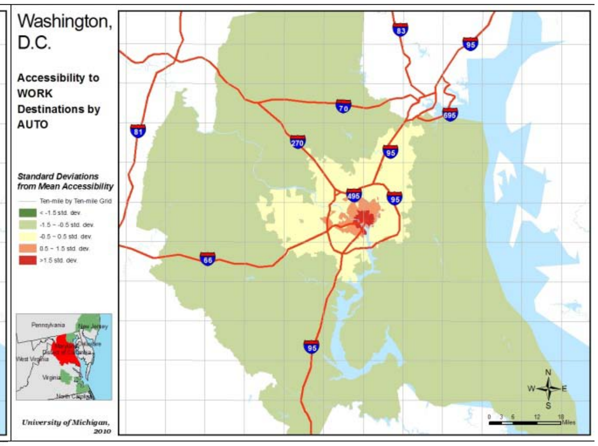
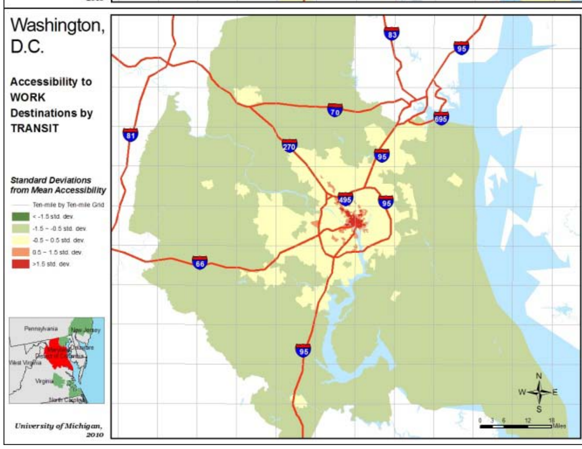
66







Appendix D: Calculating Accessibility Scores with the Gravity Model

The basic form of the gravity model is the following:

$$(A_i)^{p,m} = \sum_j O_j{}^p F(c_{ij})^{p,m} \tag{1}$$

Where,

$(A_i)^{p,m}$ is the accessibility index for people living in zone *i*, for trip purpose *p* (work and nonwork), and for travel mode *m* (auto or transit);

O_j^p is the number of opportunities in destination zone *j* based on a set of destinations determined by *trip* purpose *p*; for work travel the value is the sum of jobs in a zone and for nonwork travel the value is the sum of nonwork attractiveness in a zone. Nonwork attractiveness is a concept that was developed to measure the likelihood of the nonwork trip attraction. Appendix F explains the definition and calculation of this term.

$F(c_{ij})^{p,m}$ is a composite impedance function capturing travel conditions across multiple metropolitan areas, associated with the cost of travel *c* for travel between zones *i* and *j*, for trip purpose *p*, and for travel by mode *m*; defined in Equation 2 below.
For metropolitan regions with a total of N zones, *i, j* = 1, 2, …, N.

The composite impedance function is given by:

$$F(C_{ij})^{p,m} = e^{-\beta^p T_{ij}^m} \quad (2)$$

Where,
e is the base of the natural logarithm;
T_{ij}^m is the travel time (minutes) between zones *i* and *j* for travel mode *m*;
β^p is a parameter empirically derived to maximize the fit between predictions of the gravity model and observed distributions of travel times for trip purpose p. For all the metropolitan regions this study developed one shared β parameter for work travel and one shared β parameter for nonwork travel. Individual work and nonwork β values were estimated for each of the 16 metropolitan regions for which complete data were available. Each β is estimated by a ordinary least squares regression transformed from the following equation:

$$N_{ij} = kv_i^{\mu}w_j^{\alpha}c_{ij}^{-\beta} \quad (3)$$

Where, N_{ij} is the number of trips from origin zone *i* to destination zone *j*; v_i^{μ} is a measure of the propensity of trips to be generated at zone *i*; w_j^{α} is a measure of the attractiveness of zone *j*; c_{ij} is a measure of the spatial separation of *i* and *j*; and *k*, *μ*, *α*, and *β* are parameters to be estimated by regression.

Values of the β parameter were negatively correlated with metropolitan population. A regression was then estimated with individual values β dependent and metropolitan population independent. For work travel, the best-fitting regression is: estimated $\beta = 0.109*\exp(-3.52*10^{-8}*\text{Population})$. For nonwork travel, the best-fitting regression is: estimated $\beta = 0.24*\exp(-3.52*10^{-8}*\text{Population})$. These two equations were then used to predict the work and nonwork β values, respectively, for each of the 38 metropolitan regions for which population data were available. The β values for the 20th largest metropolitan region, roughly the median in this study's sample in size terms were then used as the unitary β values for accessibility calculation in this research (0.10157 for work and 0.2307 for nonwork).

Appendix E: Decomposition of Accessibility Differences

The following steps illustrate the mathematical derivation of the two effects in the decomposition of the difference in accessibility between two MPOs X and Y, where MPO Y is the base MPO and MPO X is the one to be compared with MPO Y. As mentioned in the text, four types of accessibility measures were calculated for each MPO where data are available. Then the distribution of accessibility by population was graphically presented using line charts, as the ones showed in Appendix A. For the decomposition purposes, the magnitude and population distribution of the same type of accessibility between two MPOs were compared. The accessibility measures were calculated at the TAZ level. For example, according to the gravity model presented in Appendix D, the accessibility of TAZ i in MPO X and Y were calculated by the two following equations respectively:

$$A_{X,i} = \sum_{j=1}^{N} O_{X,j} \cdot F(C_{X,ij}) \qquad \text{(E-1)}$$

$$A_{Y,i} = \sum_{j=1}^{M} O_{Y,j} \cdot F(C_{Y,ij}) \qquad \text{(E-2)}$$

Where, $A_{X,i}$ is the accessibility for people who live in Zone i in MPO X. N is the total number of TAZs in MPO X. $O_{X,j}$ is the total number of opportunities in destination Zone j, and $F(C_{X,ij})$ is the composite impedance function, both are defined as in Appendix D above. Similar notations apply to (E-2) for MPO Y. Using the TAZ-based accessibility measures as the starting point, the total difference between accessibility of MPO X and that of MPO Y was estimated as the accumulated accessibility for all populations in MPO X and that in MPO Y, which is computed using the following formula:

$$Total\ Difference = \int_0^1 A_{X,i} \cdot d_{p(X,i)} - \int_0^1 A_{Y,i} \cdot d_{p(Y,i)}$$

Where, $p(X,i)$ is the share of population residing in zone i to the total population of MPO X, which varies from 0 to 1. $p(Y,i)$ is defined similarly for MPO Y. This total difference in accessibility between two MPOs is caused by two major factors: the travel speed and the land use pattern, or namely the speed effect and the proximity effect, the calculation of which is elaborated in the text below.

(1) Derivation of Speed Effect

Speed effect, by definition, denotes the effect of travel speed on accessibility scores of a metropolitan area. Changes in travel speed will not only affect the magnitude of accessibility but may also affect the distribution of accessibility across space, because the gravity measure of accessibility is not a linear function of speed. To derive the speed effect, a two-step task needed to be completed: 1) to measure the change in accessibility at TAZ level caused by speed difference, and 2) to aggregate the total speed effect at MPO level.

In the first step, the "hypothetical" accessibility of every TAZ in MPO X was calculated as if the travel speed in MPO were identical to that in MPO Y by transforming the zone-to-zone travel times in MPO X. This hypothetical accessibility for Zone i in MPO X, $A'_{X,i}$, is calculated using the following formula, a variance to the basic gravity model (E-1) presented above.

$$A'_{X,i} = \sum_{j=1}^{N} O_{X,j} F(C'_{X,ij}) = \sum_{j=1}^{N} O_{X,j} F\left(\frac{D_{X,ij}}{S'_{X,ij}}\right) \quad \text{(E-3)}$$

Where, $C'_{X,ij}$ is the transformed travel time between origin zone i and destination zone j in MPO X. $D_{X,ij}$ is the Euclidean distance between the centroid of these two zones. $S'_{X,ij}$ is the transformed travel speed between the two zones, which is calculated in:

$$S'_{X,ij} = \frac{S_{X,ij} - \overline{S_X}}{\sigma_{S_X}} \cdot \sigma_{S_Y} + \overline{S_Y} \quad \text{(E-4)}$$

Where, $S_{X,ij}$ is the actual travel speed between zone i and j in MPO X. $\overline{S_X}$ is the mean of all zone-to-zone travel speeds in MPO X, and $\overline{S_Y}$ is the mean of all zone-to-zone travel speeds in MPO Y. σ_{S_X} is the standard deviation of the distribution of all zone-to-zone travel speeds in MPO X, and σ_{S_Y} is the standard deviation of the distribution of all zone-to-zone travel speeds in MPO Y.

The idea of this formula (E-4) is to transform the zone-to-zone travel speed in MPO X in a fashion that the mean and variance of the speed in MPO X are almost identical to that in MPO Y.

The rationale came from the observation that the distribution of zone-to-zone travel speeds in almost every MPO in this study is very similar to that of a normal distribution. (E-4) yields a distribution of $S'_{X,ij}$ that follows a normal distribution with mean $\overline{S_Y}$ and standard deviation σ_{S_Y}, which would be almost identical to the distribution of $S_{Y,ij}$. Therefore, that the accessibility calculated from (E-3), $A'_{X,i}$, is interpreted as the hypothetical accessibility of MPO X if the zone-to-zone travel speed were the same as in MPO Y. The hypothetical accessibility by population in MPO X was then plotted and compared that to the actual accessibility by population chart. The difference between this hypothetical accessibility line and the actual accessibility line is the speed effect in the decomposition of the accessibility difference between MPO X and MPO Y. Mathematically, the size of such speed effect is computed as:

$$Speed\ Effect = \int_0^1 A_{X,i} \cdot d_{p(X,i)} - \int_0^1 A'_{X,i} \cdot d_{p(X,i)}$$

(2) Derivation of Proximity Effect

After the speed effect was separated out, the remaining difference between the hypothetical accessibility of MPO X and the accessibility of MPO Y is considered to be caused by the difference in land arrangement between the two MPOs, thus would be considered as the proximity Effect. That is:

$$\begin{aligned} Proximity\ Effect &= Total\ effect - Speed\ Effect \\ &= \left(\int_0^1 A_{X,i} \cdot d_{p(X,i)} - \int_0^1 A_{Y,i} \cdot d_{p(Y,i)}\right) - \left(\int_0^1 A_{X,i} \cdot d_{p(X,i)} - \int_0^1 A'_{X,i} \cdot d_{p(X,i)}\right) \\ &= \int_0^1 A'_{X,i} \cdot d_{p(X,i)} - \int_0^1 A_{Y,i} \cdot d_{p(Y,i)} \end{aligned}$$

Appendix F: Developing a Nonwork Attractiveness Index

To weight jobs according to their trip-attracting capacity requires several steps. First, the distribution of nonwork trips in a given metropolitan area was assumed to match the nationwide distribution of trips in the NHTS. Work trips make up 17.7 percent of all national person trips, and that nonwork trips make up 82.3 percent of all national person trips. Then, by using the total number of jobs in a metropolitan region, nonwork "trip draws"– a term designed to capture the attractive capacity of a job at a nonwork destination – can be calculated as follows:

$$TD_m = J_m \left(\frac{0.823}{0.177}\right) \qquad (3)$$

Where, TD_m is the number of trip draws for metropolitan region *m*; J_m is the number of jobs in metropolitan region *m*; and the fraction is the ratio of the national share of nonwork to work trips.

The second step was to distribute the total trip draws among the 24 categories of trip purposes, assuming that the share of all trips for any trip purpose is the same in a metropolitan region as it is nationwide:

$$TD_t = TD_m (F_t) \qquad (4)$$

Where, TD_t is the number of trip draws in a metropolitan region for trip purpose *t*; F_t is the trip purpose weighting factor for a set of k nonwork trip purposes, representing the proportion of all national trips that are made for trip purpose k, such that $F_1 + F_2 + \ldots + F_k = 0.823$ = the proportion of all national trips that are made for nonwork purposes.

A third step is to express the trip draws for each trip purpose on a per job basis:

$$TDPJ_t = \frac{TD_t}{J_t} \qquad (5)$$

Where, $TDPJ_t$ is the trip draws per job for trip purpose *t*; J_t is the number of jobs in the metropolitan region associated with trip purpose t; for the trip purpose "visiting friends and relatives," the indicator is not jobs but population, so J_t for this trip purpose is the residential population in the metropolitan region.

The fourth and final step is to calculate the nonwork attractiveness of each zone:

$$NWA_i = \sum_{t=1}^{k} (TDPJ_t) J_{it} \quad (6)$$

Where, NWA_i is the nonwork attractiveness index at zone *i*; $TDPJ_t$ is as defined in Equation 5; J_{it} is the number of jobs in zone *i* associated with trip purpose *t*; for the trip purpose "visiting friends and relatives," the indicator is not jobs but population, so J_{it} for this trip purpose is the residential population in zone *i*. k is the number of categories of nonwork trip purposes, equal to 24.

Table 6: Nonwork Destination Categories and Associated Businesses' NAICS Codes

Nonwork Destination Category	NAICS Code	NAICS DESCRIPTION
1	441110	New Car Dealers
	441120	Used Car Dealers
	441210	Used Car Dealers
	441221	Motorcycle, ATV, and Personal Watercraft Dealers
	441222	Boat Dealers
	441229	All Other Motor Vehicle Dealers
	441310	Automotive Parts and Accessories Stores
	441320	Tire Dealers
	442110	Furniture Stores
	442210	Floor Covering Stores
	442291	Window Treatment Stores
	442299	All Other Home Furnishings Stores
	443111	Household Appliance Stores
	443112	Radio, Television, and Other Electronics Stores
	443120	Computer and Software Stores
	443130	Camera and Photographic Supplies Stores
	444110	Home Centers
	444120	Paint and Wallpaper Stores
	444130	Hardware Stores
	444190	Other Building Material Dealers
	444210	Outdoor Power Equipment Stores
	444220	Nursery, Garden Center, and Farm Supply Stores
	445110	Supermarkets and Other Grocery (except Convenience) Stores
	445120	Convenience Stores

	445210	Meat Markets
	445220	Fish and Seafood Markets
	445230	Fruit and Vegetable Markets
	445291	Baked Goods Stores
	445292	Confectionery and Nut Stores
	445299	All Other Specialty Food Stores
	445310	Beer, Wine, and Liquor Stores
	446110	Pharmacies and Drug Stores
	446120	Cosmetics, Beauty Supplies, and Perfume Stores
	446130	Optical Goods Stores
	446191	Food (Health) Supplement Stores
	446199	All Other Health and Personal Care Stores
	448110	Men's Clothing Stores
	448120	Women's Clothing Stores
	448130	Children's and Infants' Clothing Stores
	448140	Family Clothing Stores
	448150	Clothing Accessories Stores
	448190	Other Clothing Stores
	448210	Shoe Stores
	448310	Jewelry Stores
	448320	Luggage and Leather Goods Stores
	451110	Sporting Goods Stores
	451120	Hobby, Toy, and Game Stores
	451130	Sewing, Needlework, and Piece Goods Stores
	451140	Musical Instrument and Supplies Stores
	451211	Book Stores
	451212	News Dealers and Newsstands
	451220	Prerecorded Tape, Compact Disc, and Record Stores
	452111	Department Stores (except Discount Department Stores)
	452112	Discount Department Stores
	452910	Warehouse Clubs and Supercenters
	452990	All Other General Merchandise Stores
	453110	Florists
	453210	Office Supplies and Stationery Stores
	453220	Gift, Novelty, and Souvenir Stores
	453310	Used Merchandise Stores
	453920	Art Dealers
	453930	Manufactured (Mobile) Home Dealers
	453991	Tobacco Stores
	453998	All Other Miscellaneous Store Retailers (except Tobacco Stores)

2	722110	Full-Service Restaurants
	722211	Limited-Service Restaurants
	722212	Cafeterias, Grill Buffets, and Buffets
	722330	Mobile Food Services
3	N/A	N/A (Note: Number of Population is considered as the number of destinations in this category)
4	491110	Postal Service
	492110	Couriers and Express Delivery Services
	522110	Commercial Banking
	522120	Savings Institutions
	522130	Credit Unions
	522190	Other Depository Credit Intermediation
	522291	Consumer Lending
	522310	Mortgage and Nonmortgage Loan Brokers
	532210	Consumer Electronics and Appliances Rental
	532220	Formal Wear and Costume Rental
	532230	Video Tape and Disc Rental
	532310	General Rental Centers
	811111	General Automotive Repair
	811112	Automotive Exhaust System Repair
	811113	Automotive Transmission Repair
	811118	Other Automotive Mechanical and Electrical Repair and Maintenance
	811121	Automotive Body, Paint, and Interior Repair and Maintenance
	811122	Automotive Glass Replacement Shops
	811191	Automotive Oil Change and Lubrication Shops
	811192	Car Washes
	811198	All Other Automotive Repair and Maintenance
	811211	Consumer Electronics Repair and Maintenance
	811212	Computer and Office Machine Repair and Maintenance
	811213	Communication Equipment Repair and Maintenance
	811219	Other Electronic and Precision Equipment Repair and Maintenance
	811411	Home and Garden Equipment Repair and Maintenance
	811412	Appliance Repair and Maintenance
	811420	Reupholstery and Furniture Repair
	811430	Footwear and Leather Goods Repair
	811490	Other Personal and Household Goods Repair and Maintenance
	812310	Coin-Operated Laundries and Drycleaners
	812320	Drycleaning and Laundry Services (except Coin-Operated)

	812910	Pet Care (except Veterinary) Services
	812921	Photofinishing Laboratories (except One-Hour)
	812922	One-Hour Photofinishing
5	611110	Elementary and Secondary Schools
	611210	Junior Colleges
	611310	Colleges, Universities, and Professional Schools
	611410	Business and Secretarial Schools
	611420	Computer Training
	611430	Professional and Management Development Training
	611511	Cosmetology and Barber Schools
	611512	Flight Training
	611513	Apprenticeship Training
	611519	Other Technical and Trade Schools
	611610	Fine Arts Schools
	611620	Sports and Recreation Instruction
	611630	Language Schools
	611691	Exam Preparation and Tutoring
	611692	Automobile Driving Schools
	611699	All Other Miscellaneous Schools and Instruction
	611710	Educational Support Services
6	713910	Golf Courses and Country Clubs
	713920	Skiing Facilities
	713940	Fitness and Recreational Sports Centers
	713950	Bowling Centers
7	512131	Motion Picture Theaters (except Drive-Ins)
	512132	Drive-In Motion Picture Theaters
	711110	Theater Companies and Dinner Theaters
	711120	Dance Companies
	711130	Musical Groups and Artists
	711190	Other Performing Arts Companies
	711211	Sports Teams and Clubs
	711212	Racetracks
	711219	Other Spectator Sports
	713110	Amusement and Theme Parks
	713120	Amusement Arcades
	713210	Casinos (except Casino Hotels)
	713290	Other Gambling Industries
	713930	Marinas
	713990	All Other Amusement and Recreation Industries
	722410	Drinking Places (Alcoholic Beverages)
8	624410	Child Day Care Services

9	447110	Gasoline Stations with Convenience Stores
	447190	Other Gasoline Stations
10	531210	Offices of Real Estate Agents and Brokers
	531320	Offices of Real Estate Appraisers
	531390	Other Activities Related to Real Estate
	532111	Passenger Car Rental
	541120	Offices of Notaries
	541191	Title Abstract and Settlement Offices
	541310	Architectural Services
	541320	Landscape Architectural Services
	541350	Building Inspection Services
	541410	Interior Design Services
	541921	Photography Studios, Portrait
	561311	Employment Placement Agencies
	561320	Temporary Help Services
	561510	Travel Agencies
	561611	Investigation Services
	562212	Solid Waste Landfill
	813930	Labor Unions and Similar Labor Organizations
	813940	Political Organizations
	813990	Other Similar Organizations (except Business, Professional, Labor, and Political Organizations)
	922110	Courts
	922120	Police Protection
	922130	Legal Counsel and Prosecution
	922140	Correctional Institutions
	922150	Parole Offices and Probation Offices
11	621111	Offices of Physicians (except Mental Health Specialists)
	621112	Offices of Physicians, Mental Health Specialists
	621210	Offices of Dentists
	621310	Offices of Chiropractors
	621320	Offices of Optometrists
	621330	Offices of Mental Health Practitioners (except Physicians)
	621340	Offices of Physical, Occupational and Speech Therapists, and Audiologists
	621391	Offices of Podiatrists
	621399	Offices of All Other Miscellaneous Health Practitioners
	621410	Family Planning Centers
	621420	Outpatient Mental Health and Substance Abuse Centers
	621491	HMO Medical Centers
	621492	Kidney Dialysis Centers
	621493	Freestanding Ambulatory Surgical and Emergency Centers

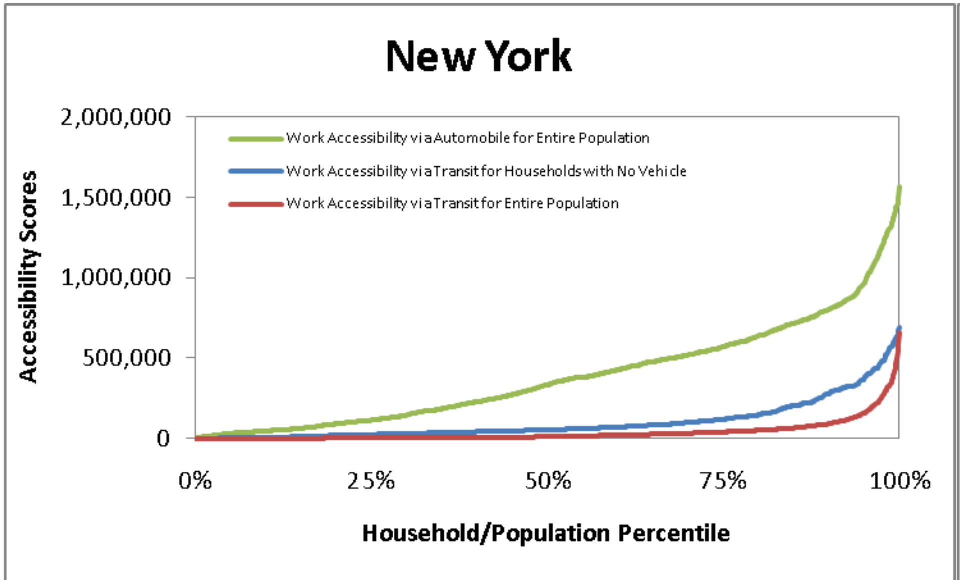
	621498	All Other Outpatient Care Centers
	621511	Medical Laboratories
	621512	Diagnostic Imaging Centers
	621610	Home Health Care Services
	621910	Ambulance Services
	621991	Blood and Organ Banks
	621999	All Other Miscellaneous Ambulatory Health Care Services
	622110	General Medical and Surgical Hospitals
	622210	Psychiatric and Substance Abuse Hospitals
	622310	Specialty (except Psychiatric and Substance Abuse) Hospitals
	623110	Nursing Care Facilities
	623210	Residential Mental Retardation Facilities
	623220	Residential Mental Health and Substance Abuse Facilities
	623311	Continuing Care Retirement Communities
	623312	Homes for the Elderly
	623990	Other Residential Care Facilities
	624120	Services for the Elderly and Persons with Disabilities
	624190	Other Individual and Family Services
	624230	Emergency and Other Relief Services
	624310	Vocational Rehabilitation Services
12	722213	Snack and Nonalcoholic Beverage Bars
13	481111	Scheduled Passenger Air Transportation
	481211	Nonscheduled Chartered Passenger Air Transportation
	483112	Deep Sea Passenger Transportation
	483114	Coastal and Great Lakes Passenger Transportation
	483212	Inland Water Passenger Transportation
	487110	Scenic and Sightseeing Transportation, Land
	487210	Scenic and Sightseeing Transportation, Water
	487990	Scenic and Sightseeing Transportation, Other
	561520	Tour Operators
	561591	Convention and Visitors Bureaus
	721110	Hotels (except Casino Hotels) and Motels
	721120	Casino Hotels
	721191	Bed-and-Breakfast Inns
	721199	All Other Traveler Accommodation
	721211	RV (Recreational Vehicle) Parks and Campgrounds
	721214	Recreational and Vacation Camps (except Campgrounds)
14	813410	Civic and Social Organizations
	921120	Legislative Bodies
	921140	Executive and Legislative Offices, Combined

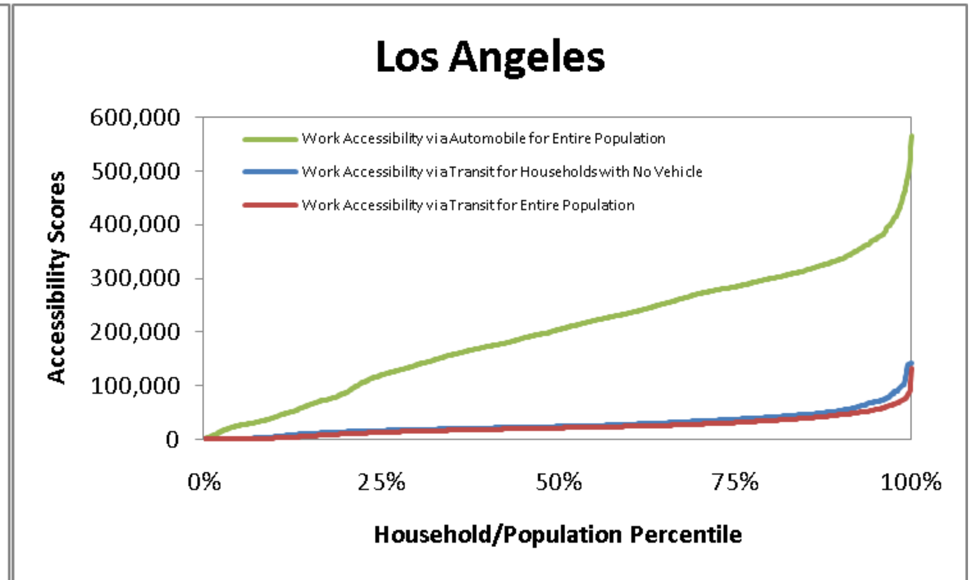
	921150	American Indian and Alaska Native Tribal Governments
	921190	Other General Government Support
	922190	Other Justice, Public Order, and Safety Activities
	923120	Administration of Public Health Programs
	923130	Administration of Human Resource Programs (except Education, Public Health, and Veterans' Affairs Programs)
	923140	Administration of Veterans' Affairs
	925110	Administration of Housing Programs
	925120	Administration of Urban Planning and Community and Rural Development
	926110	Administration of General Economic Programs
	926150	Regulation, Licensing, and Inspection of Miscellaneous Commercial Sectors
15	519120	Libraries and Archives
	712110	Museums
	712120	Historical Sites
	712130	Zoos and Botanical Gardens
	712190	Nature Parks and Other Similar Institutions
16	812111	Barber Shops
	812112	Beauty Salons
	812113	Nail Salons
	812191	Diet and Weight Reducing Centers
	812199	Other Personal Care Services
17	453910	Pet and Pet Supplies Stores
	541940	Veterinary Services
18	541110	Offices of Lawyers
	541199	All Other Legal Services
	541211	Offices of Certified Public Accountants
	541213	Tax Preparation Services
	541219	Other Accounting Services
19	812210	Funeral Homes and Funeral Services
	812220	Cemeteries and Crematories
	813110	Religious Organizations

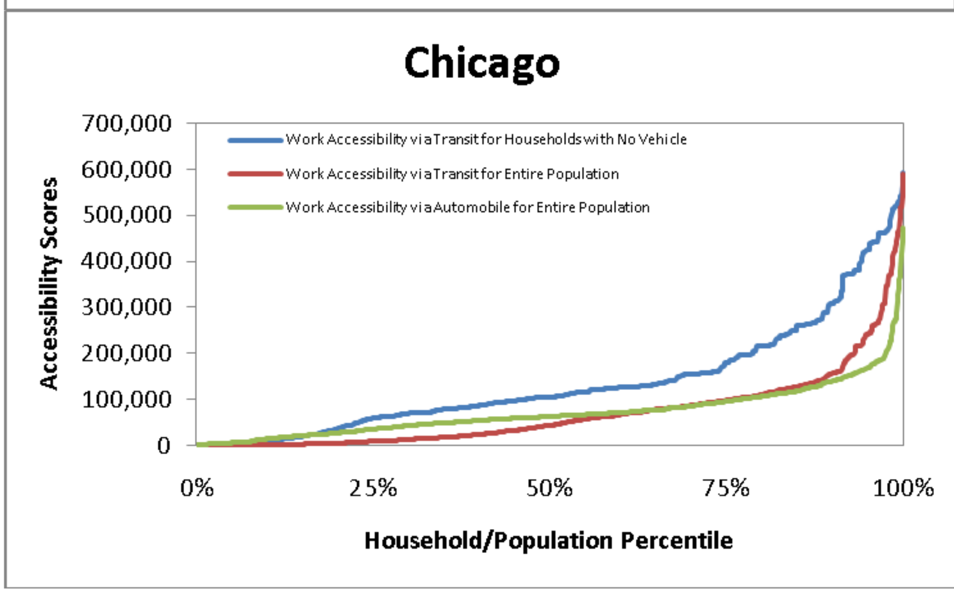
Table 7: Nonwork Destination Categories and Associated NHTS Trip Categories

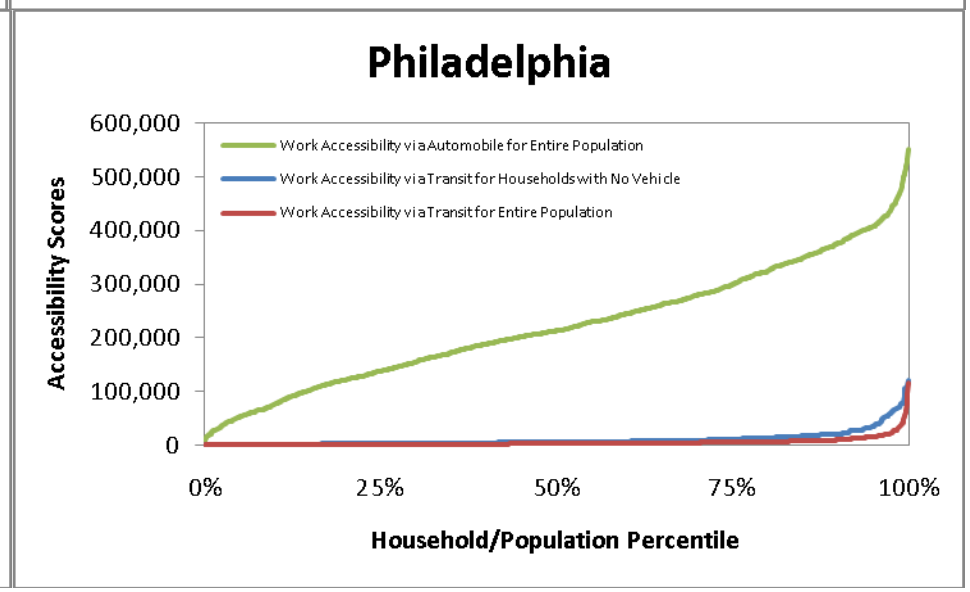
Nonwork Destination Category	Linked Trip Category and Description in 2001 NHTS	Total Trips in NHTS Sample (Millions)	Share of Nonwork Trips
1	(40) Buy goods: groceries/clothing/hardware store and (41) Shopping/Errands	55,497	28.75%
2	(82) Get/eat meal, (80) Meals, and (81) Social Event	24,947	12.92%
3	(53) Visit friends/relatives	21,790	11.29%
4	(42) Buy services: video rentals/dry cleaner/post office/carservice/bank	13,414	6.95%
5	(21) Go to school as student	12,581	6.52%
6	(51) Go to gym/exercise/play sports	13,787	7.14%
7	(54) Go out/hang out: entertainment/theater/sports event/goto bar	8,199	4.25%
8	(24) OS - Day care	1,947	1.01%
9	(43) Buy gas	6,527	3.38%
10	(60) Family personal business/obligations	6,123	3.17%
11	(30) Medical/dental services	5,591	2.90%
12	(83) Coffee/ice cream/snacks	2,612	1.35%
13	(52) Rest or relaxation/vacation	2,007	1.04%
14	(65) Attend meeting: PTA/home owners association/local government	1866	0.97%
15	(55) Visit public place: historical site/museum/park/library and (23) Go to Library: School Related	2,451	1.27%
16	(63) Use personal services: grooming/haircut/nails	1530	0.79%
17	(64) Pet care: walk the dog/vet visits	1,681	0.87%
18	(61) Use professional services: attorney/accountant	952	0.49%
19	(22) Go to religious activity and (20) School/Religious Activity	9,525	4.93%
	Total Non-Work Trips	**193,027**	**100.00%**

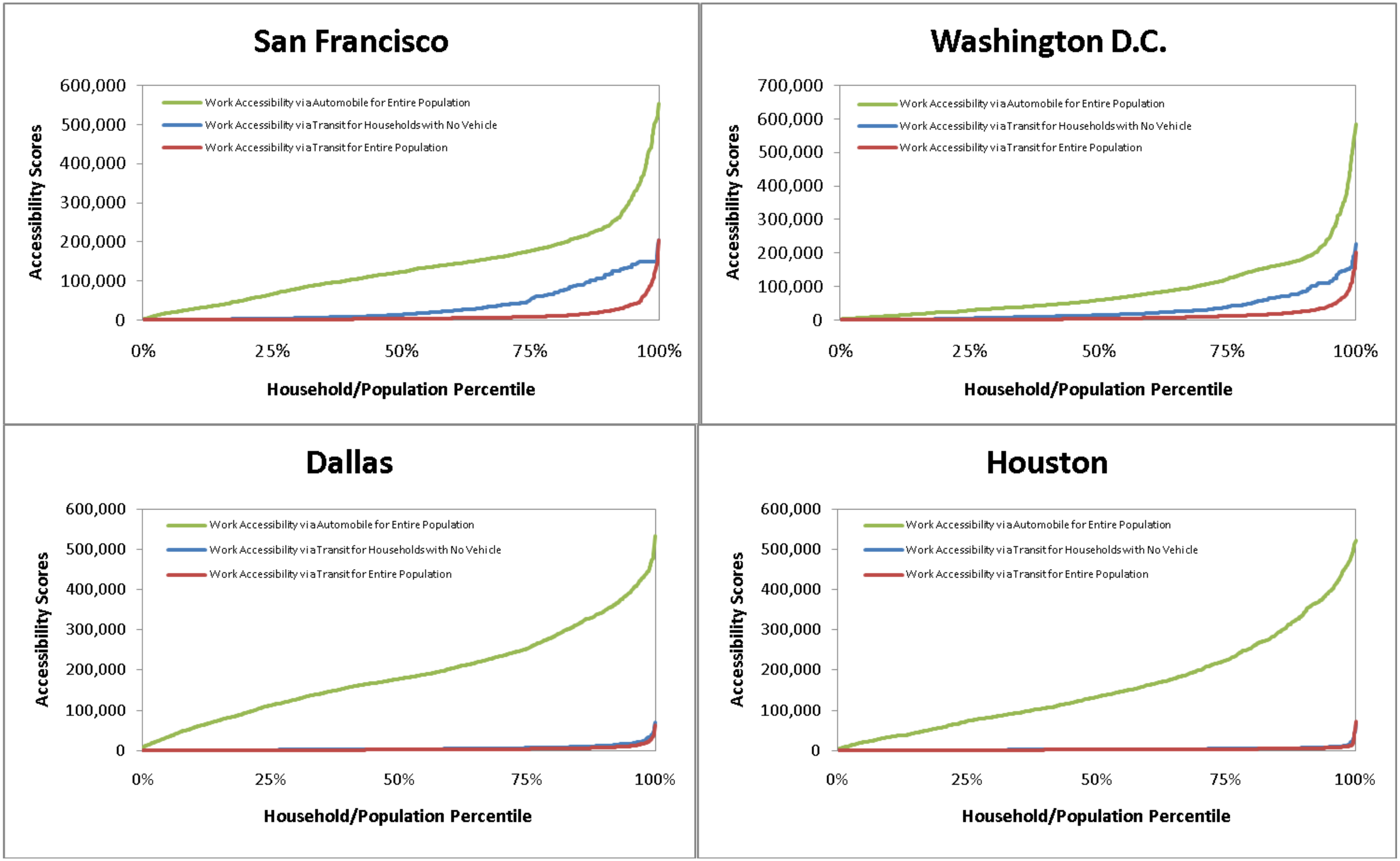
Appendix G: Gap Analysis between Households with and without Vehicles for the 27 Available Metropolitan Regions


New York
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
Accessibility Scores
2,000,000
1,500,000
1,000,000
500,000
0
0%
25%
50%
75%
100%
Household/Population Percentile

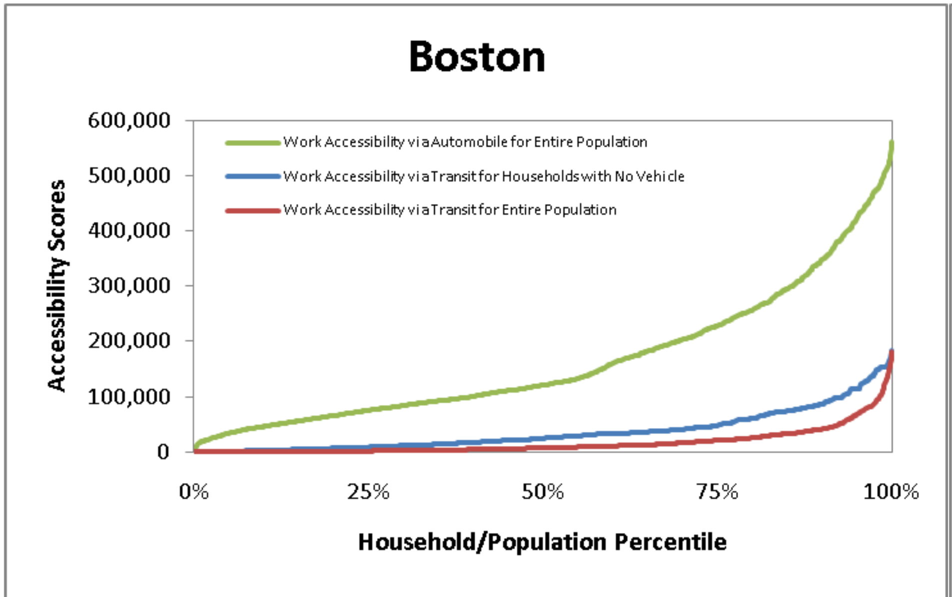

Los Angeles
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
Accessibility Scores
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Household/Population Percentile

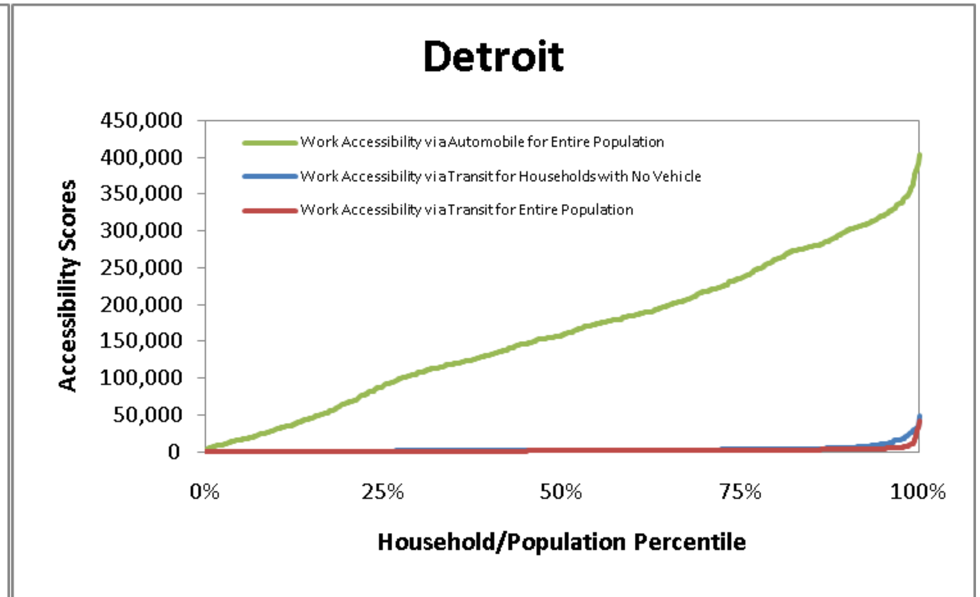

Chicago
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
Work Accessibility via Automobile for Entire Population
Accessibility Scores
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Household/Population Percentile

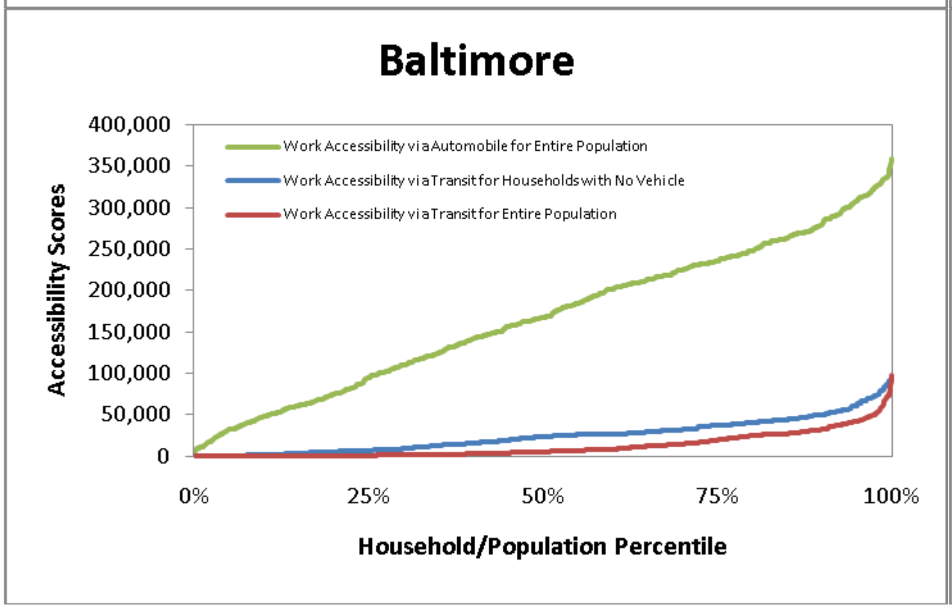

Philadelphia
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
Accessibility Scores
600,000
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Household/Population Percentile

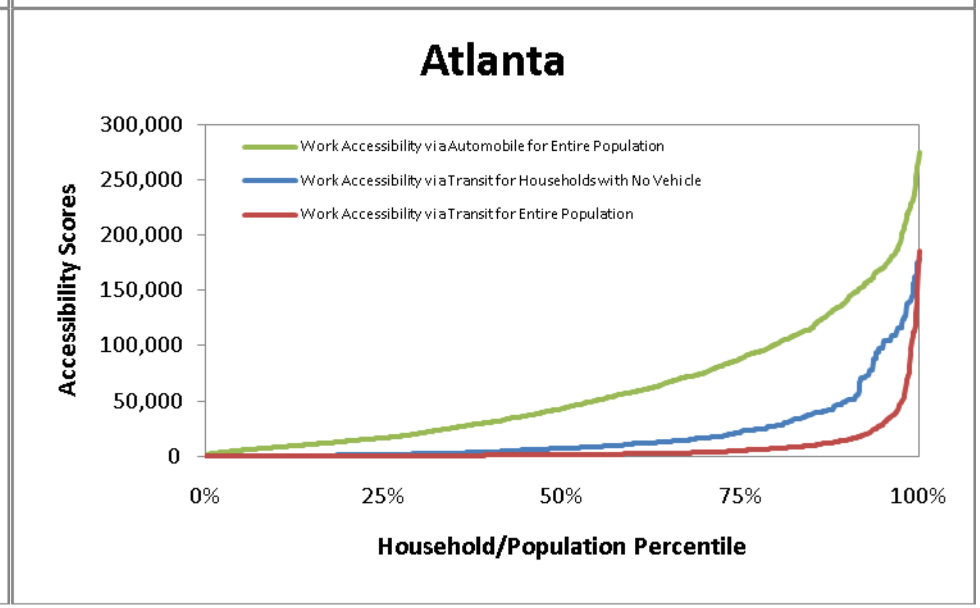


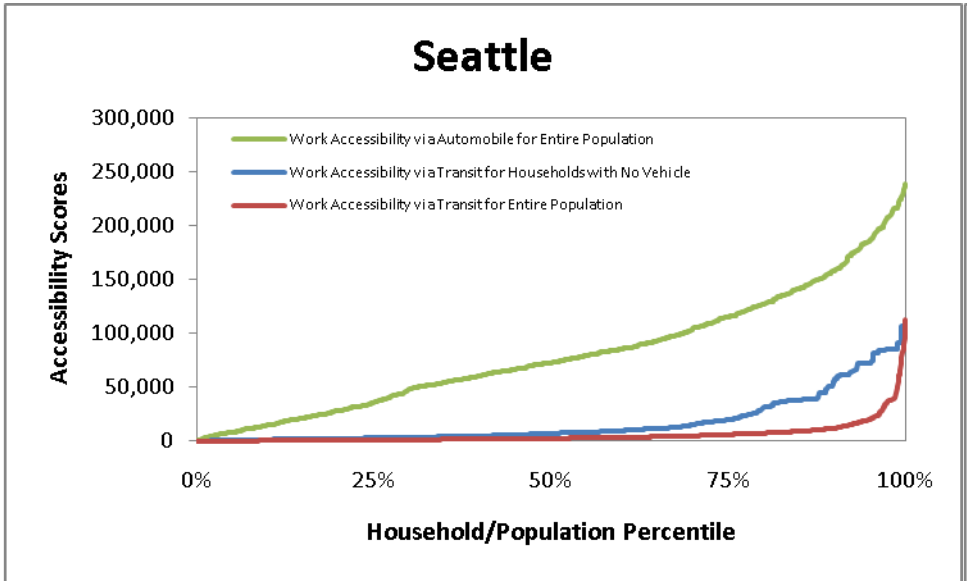
San Francisco
Washington D.C.
Dallas
Houston
Accessibility Scores
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000

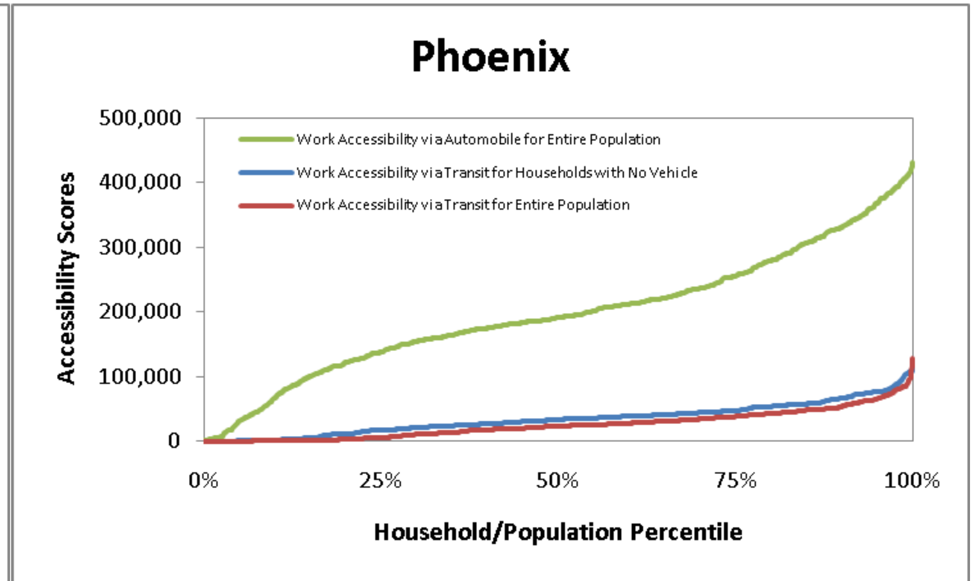

Boston
600,000
500,000
400,000
300,000
200,000
100,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

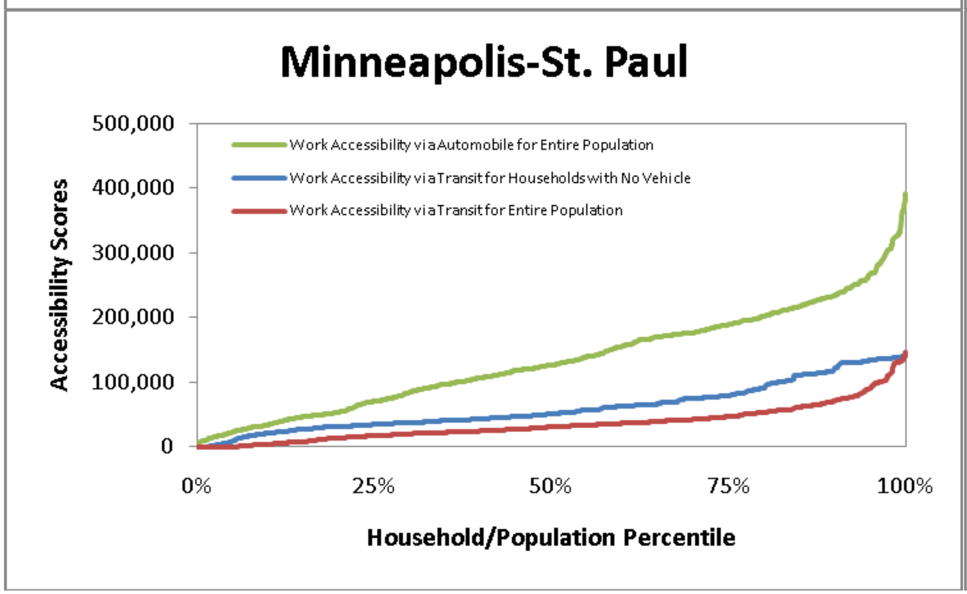

Detroit
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

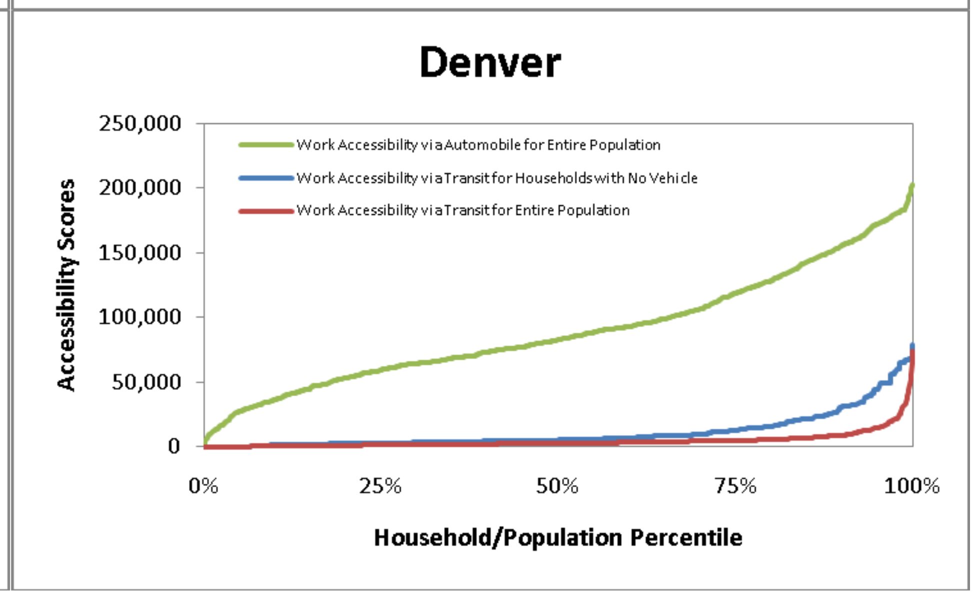

Baltimore
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

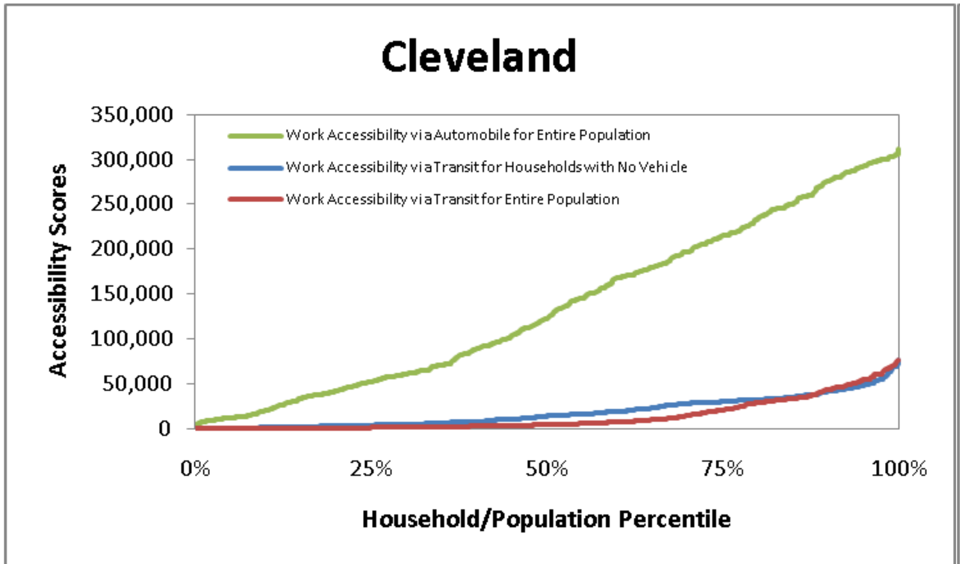

Atlanta
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

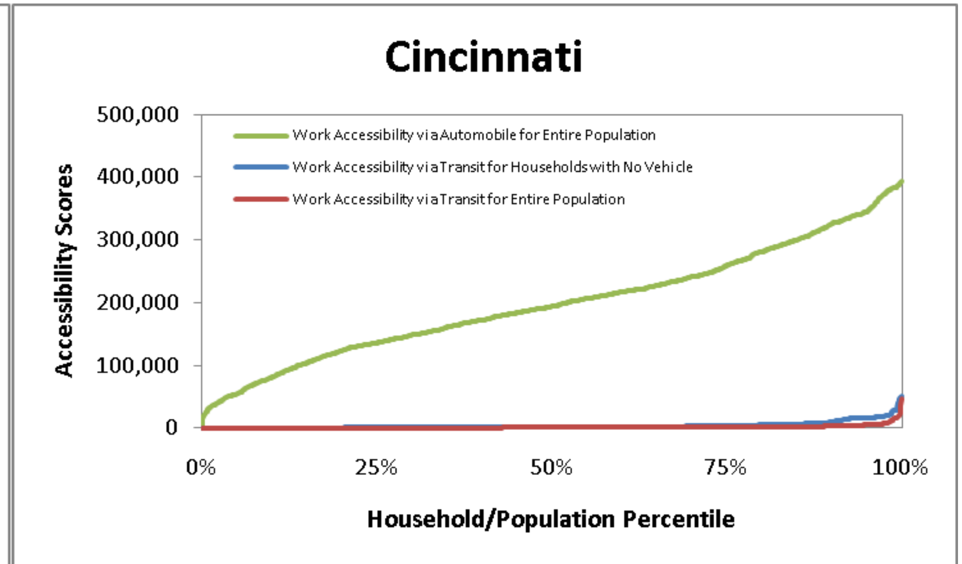

Seattle
Accessibility Scores
300,000
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

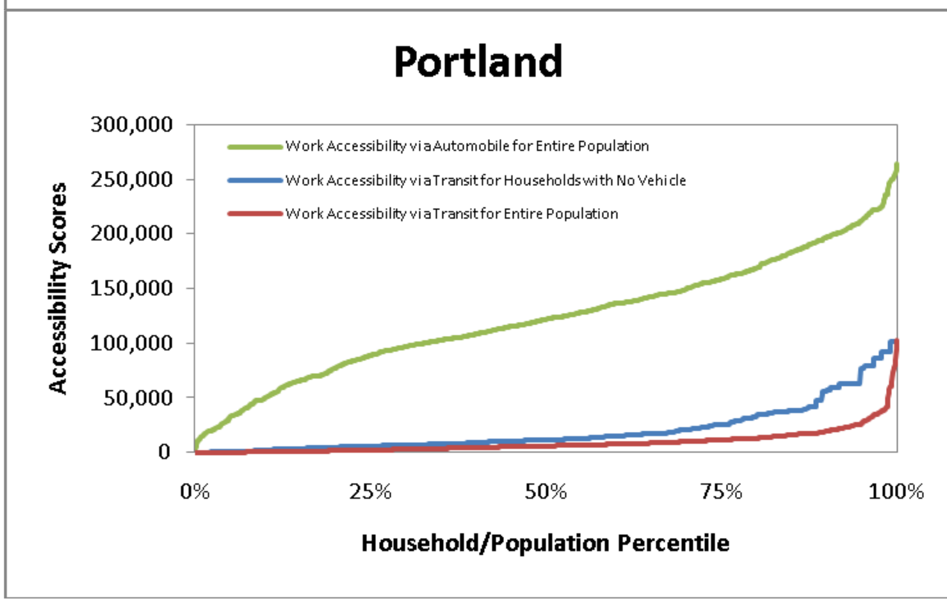

Phoenix
Accessibility Scores
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

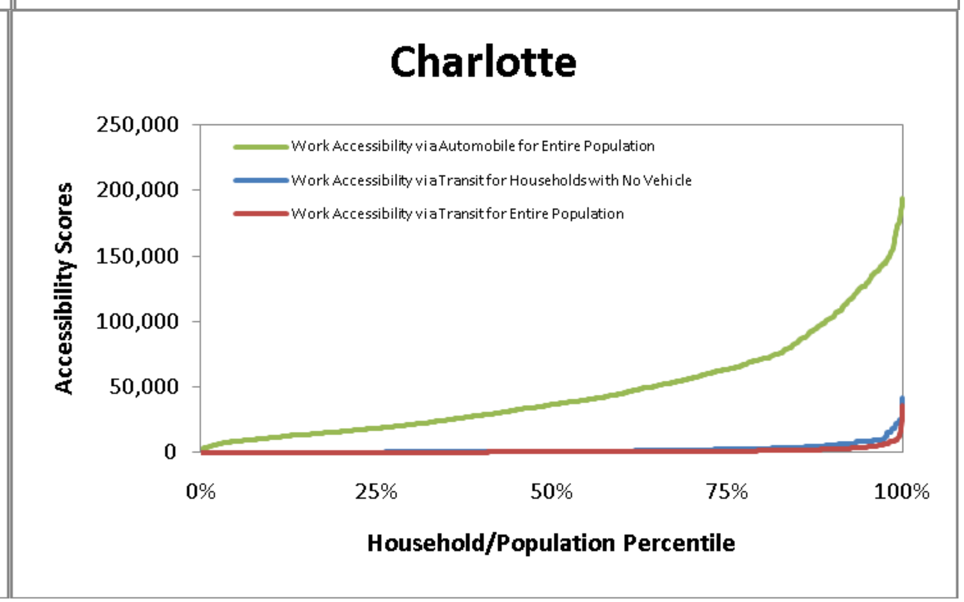

Minneapolis-St. Paul
Accessibility Scores
500,000
400,000
300,000
200,000
100,000
0
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

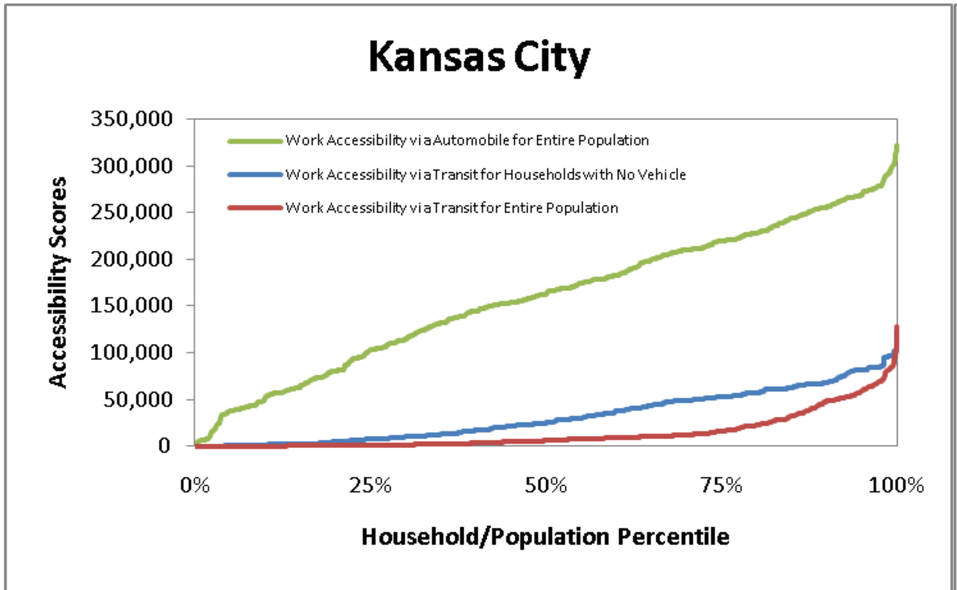

Denver
Accessibility Scores
250,000
200,000
150,000
100,000
50,000
0
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

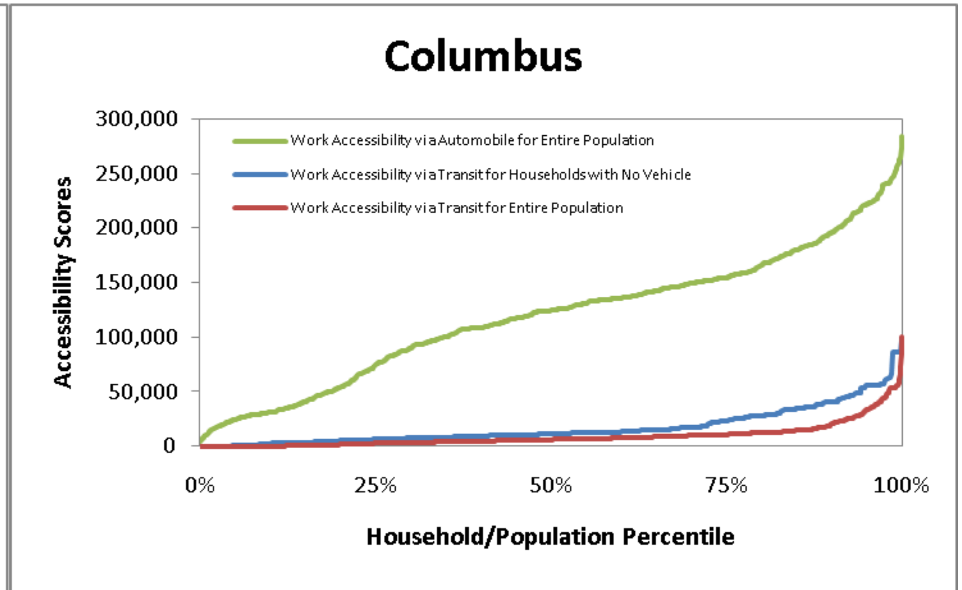

Cleveland
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

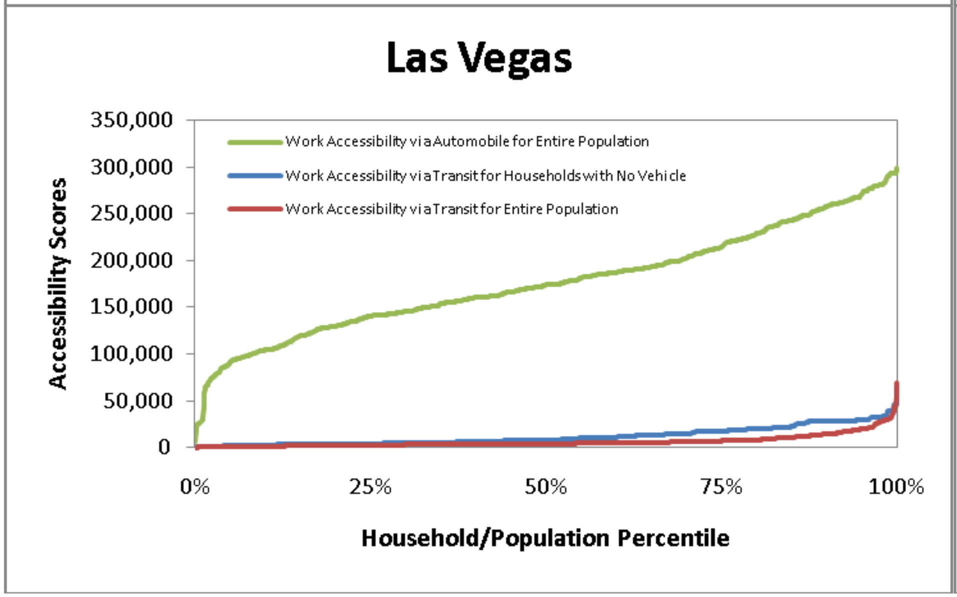

Cincinnati
500,000
400,000
300,000
200,000
100,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

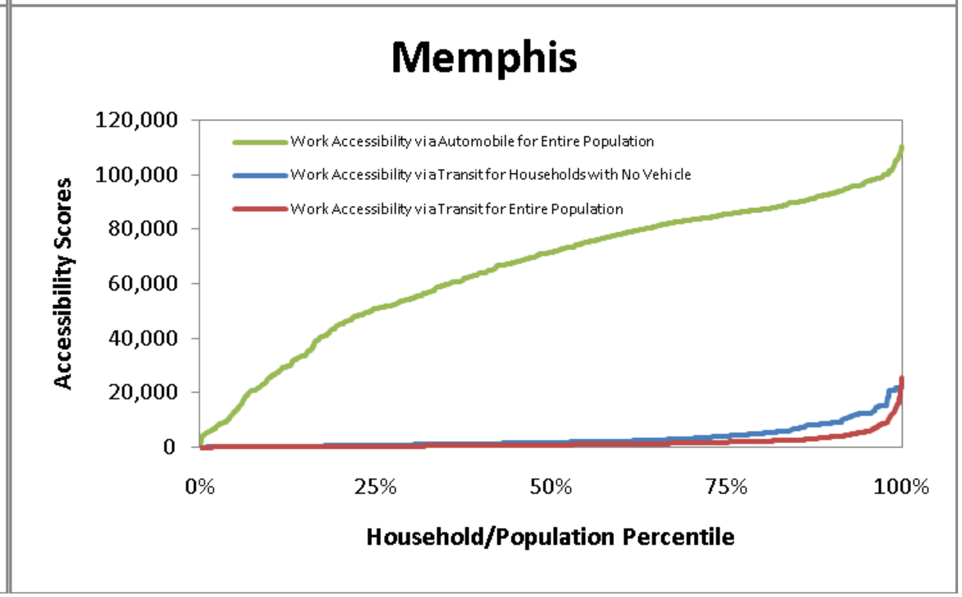

Portland
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

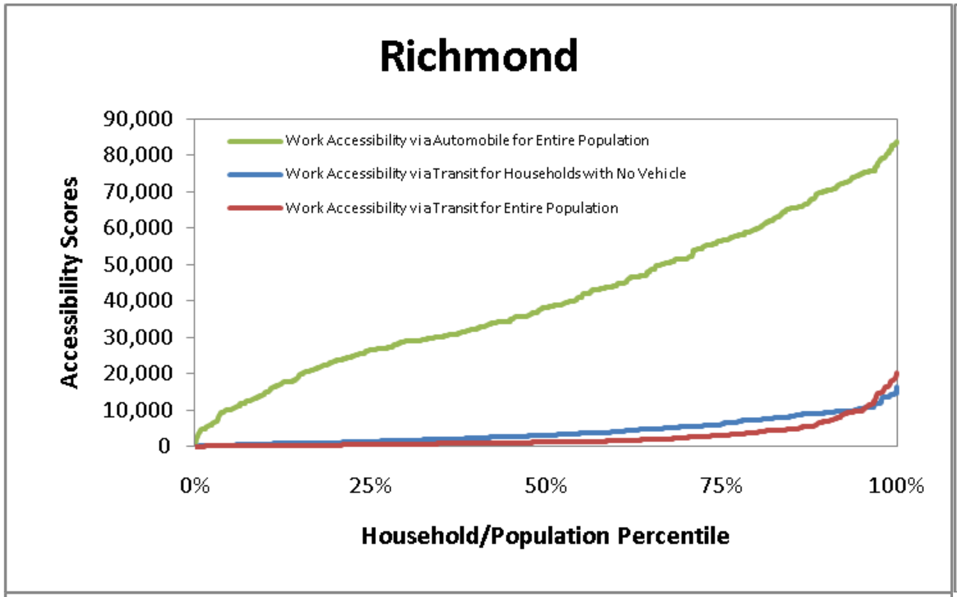

Charlotte
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

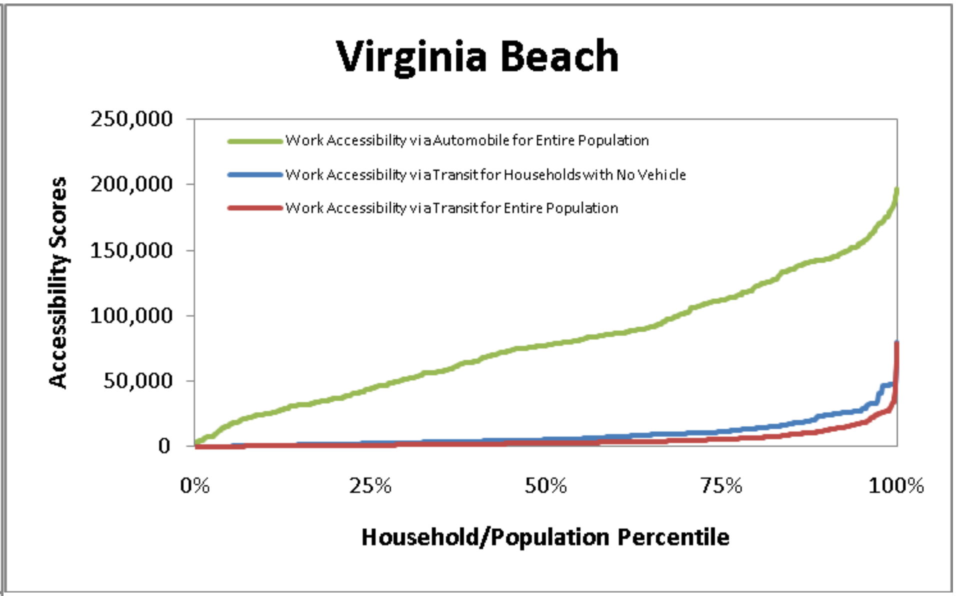

Kansas City
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

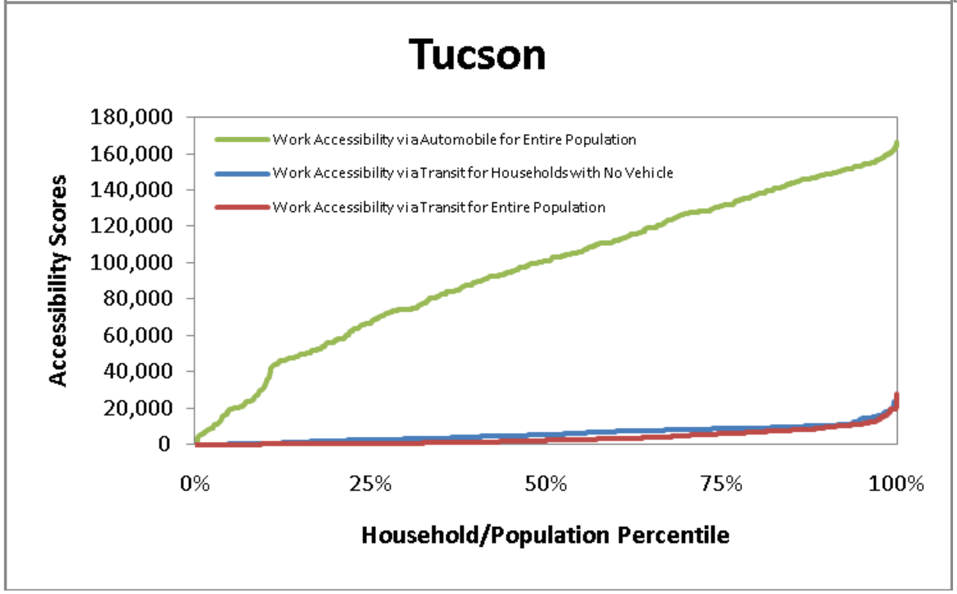

Columbus
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population


Las Vegas
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

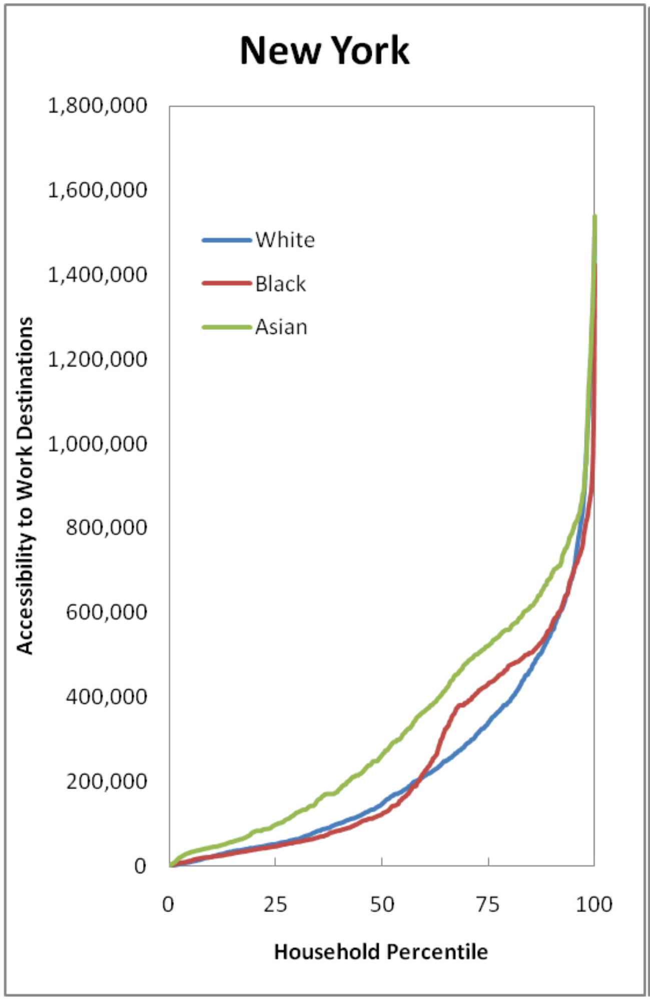

Memphis
120,000
100,000
80,000
60,000
40,000
20,000
0
Accessibility Scores
0%
25%
50%
75%
100%
Household/Population Percentile
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population

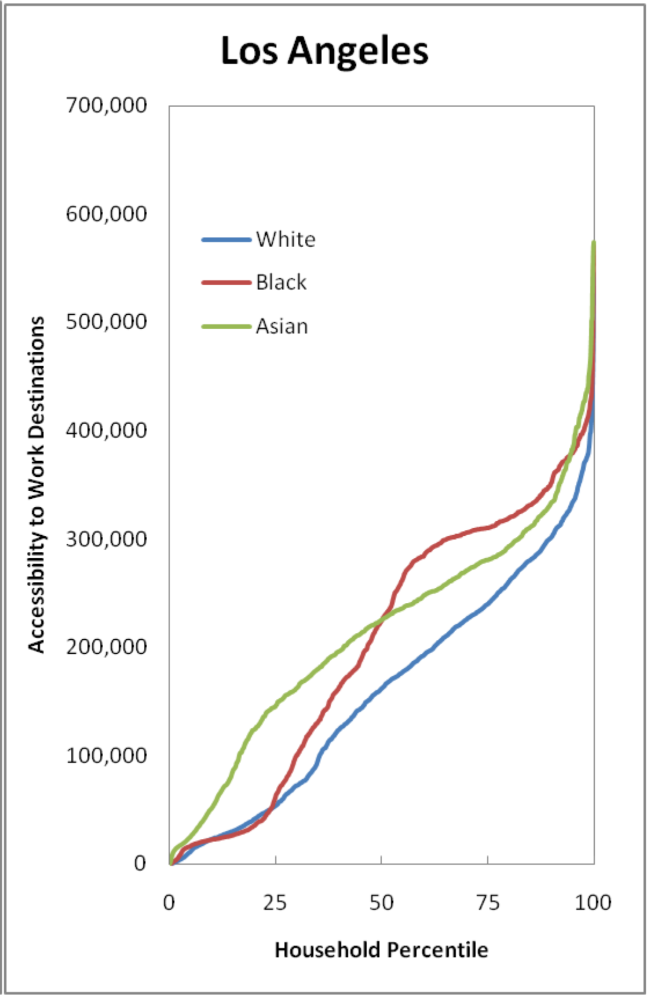

Richmond
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

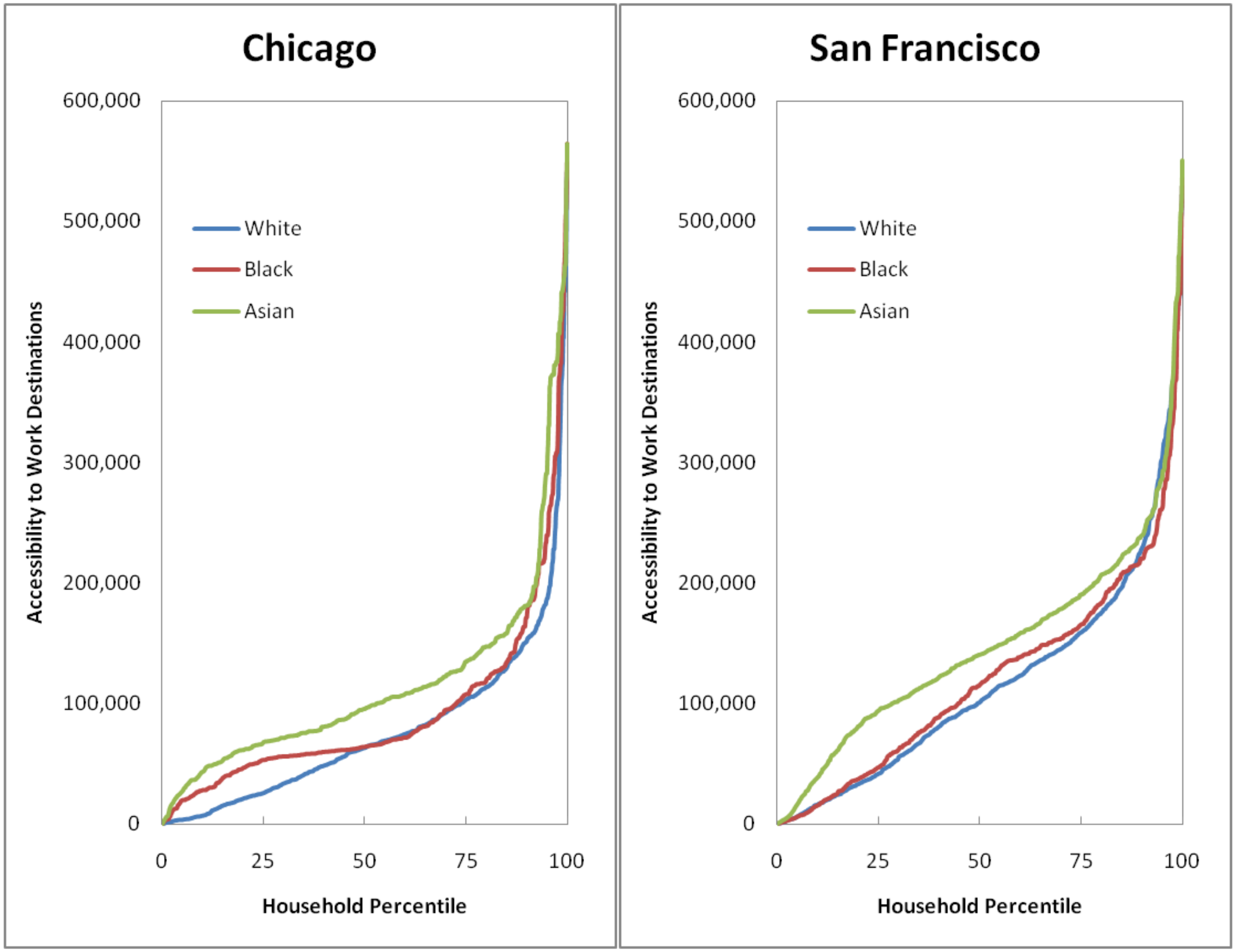

Virginia Beach
250,000
200,000
150,000
100,000
50,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

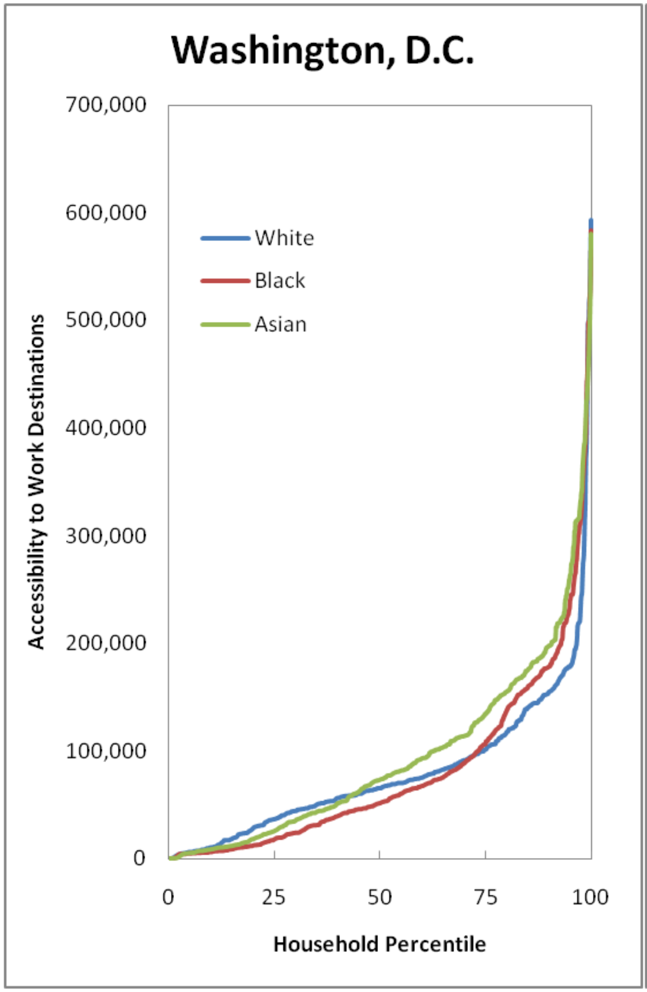

Tucson
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Accessibility Scores
Work Accessibility via Automobile for Entire Population
Work Accessibility via Transit for Households with No Vehicle
Work Accessibility via Transit for Entire Population
0%
25%
50%
75%
100%
Household/Population Percentile

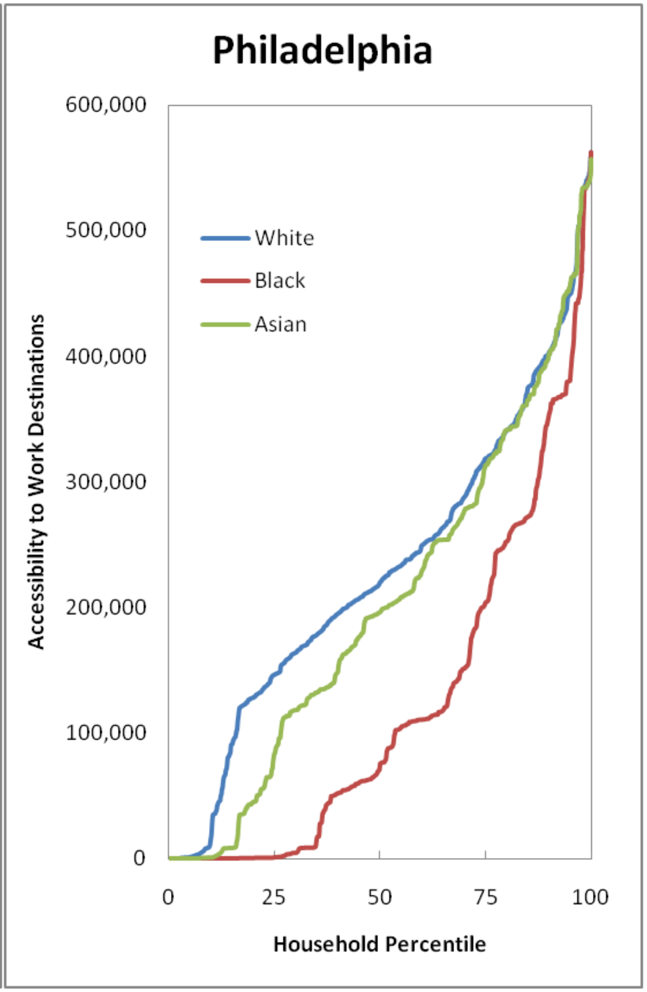
Appendix H: Equity Comparison of Work Accessibility by Race for the 26 Available Metropolitan Regions

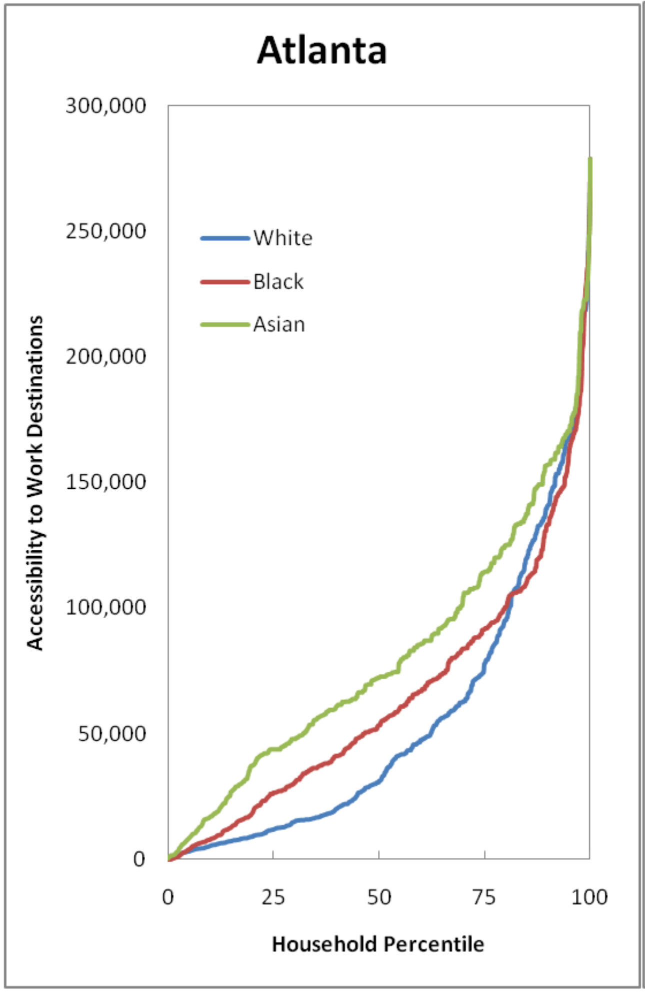

New York
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

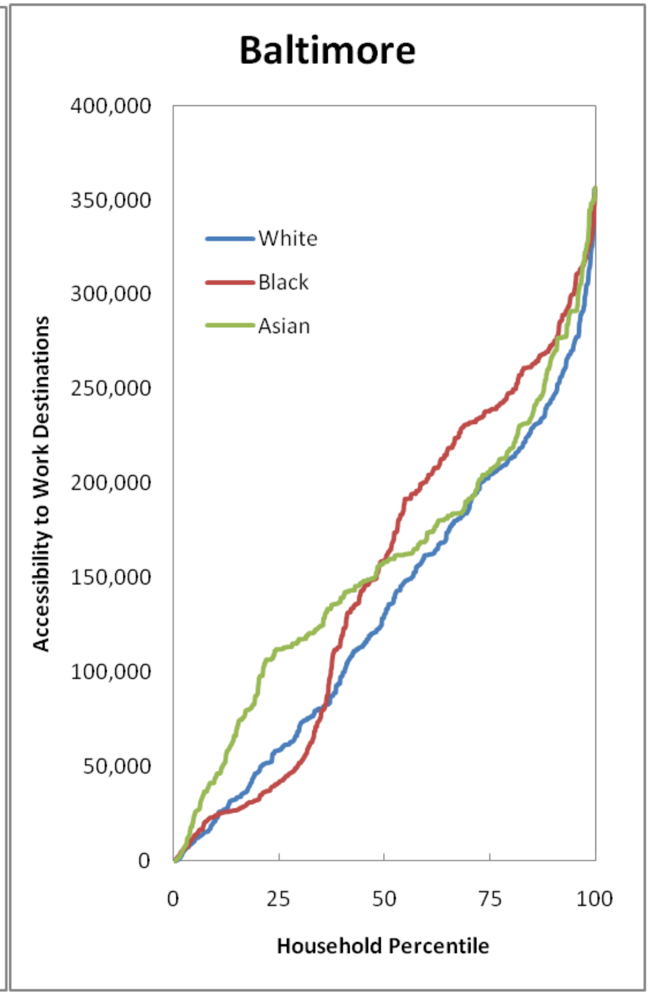

Los Angeles
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

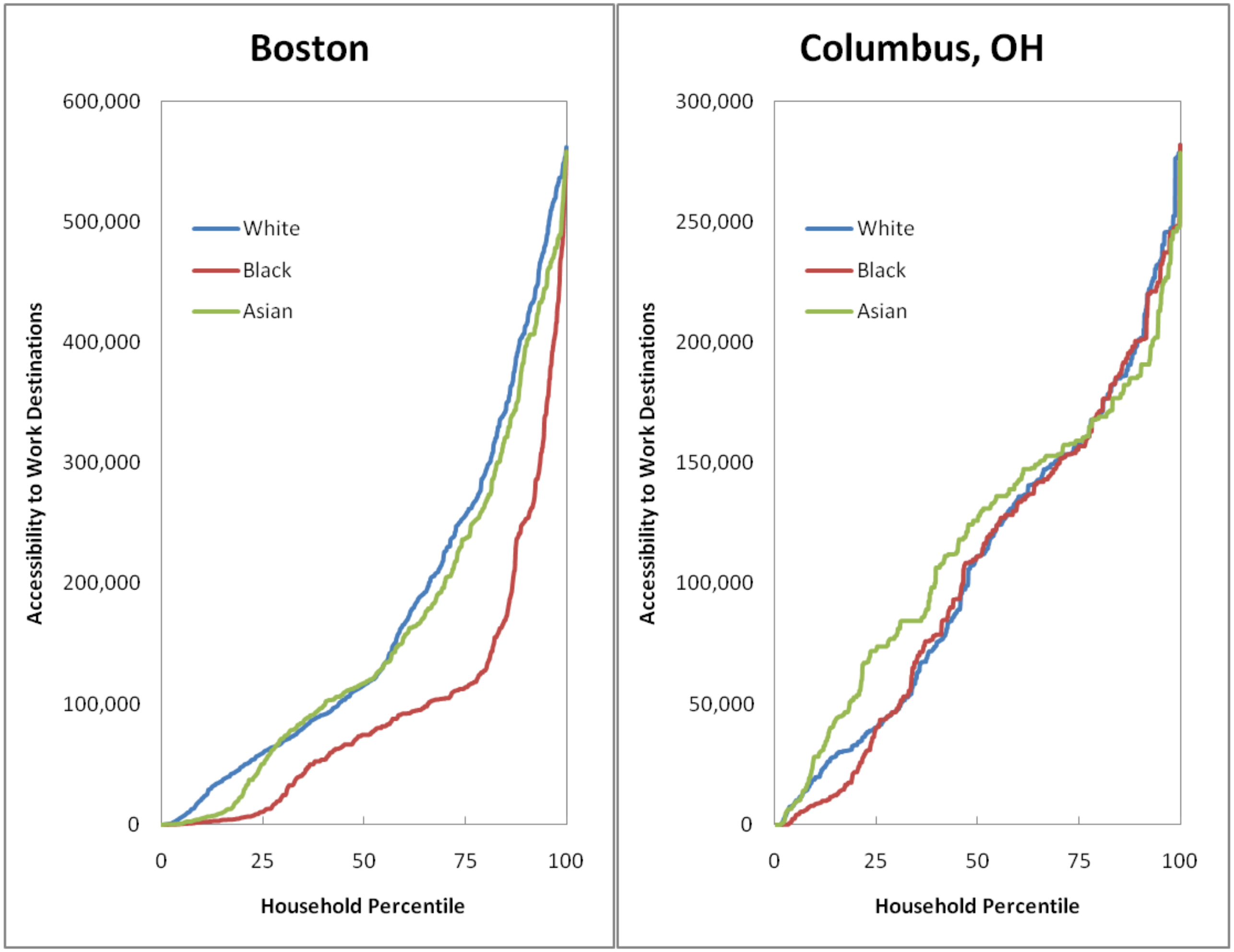

Chicago
San Francisco
600,000
500,000
400,000
300,000
200,000
100,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

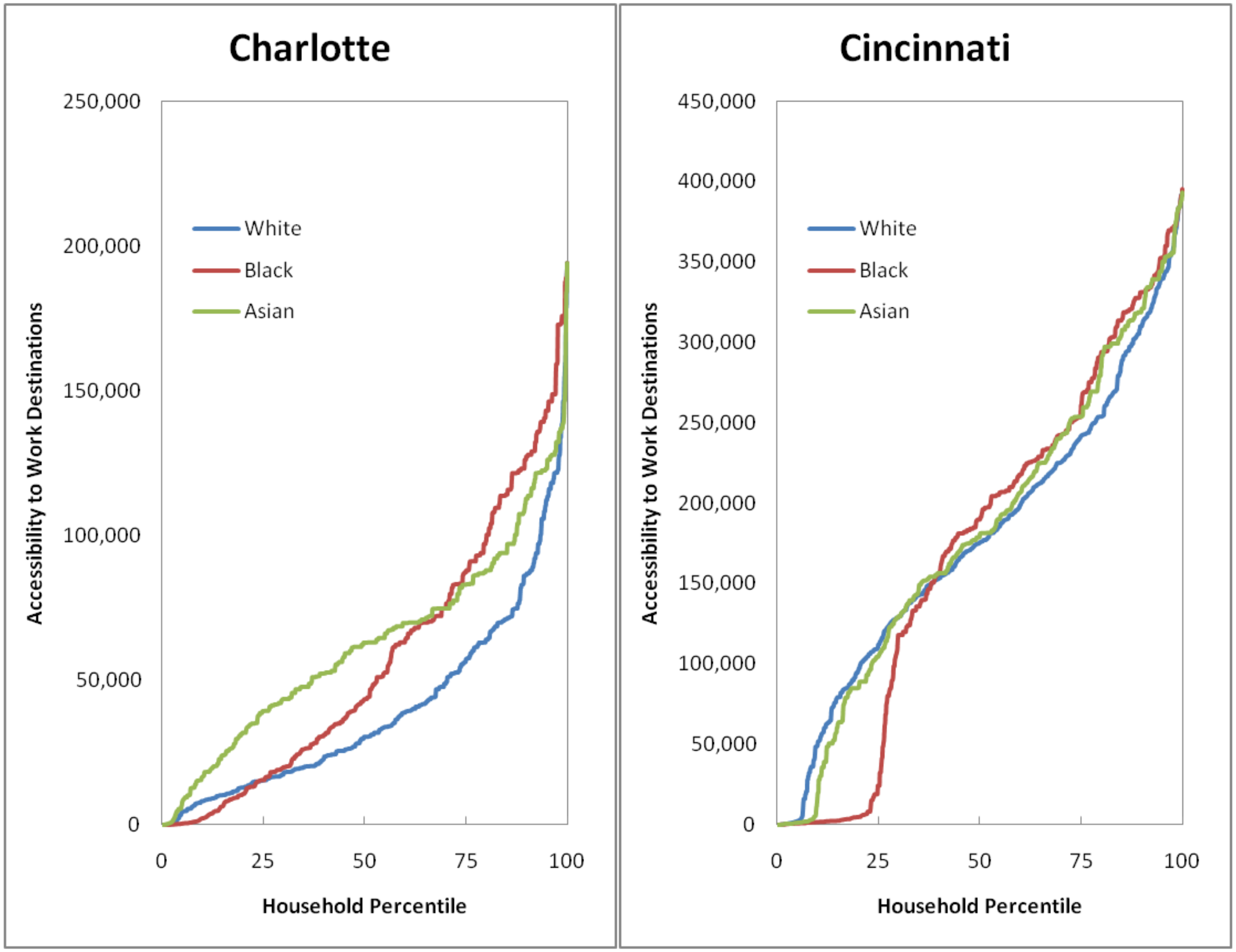

Washington, D.C.
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

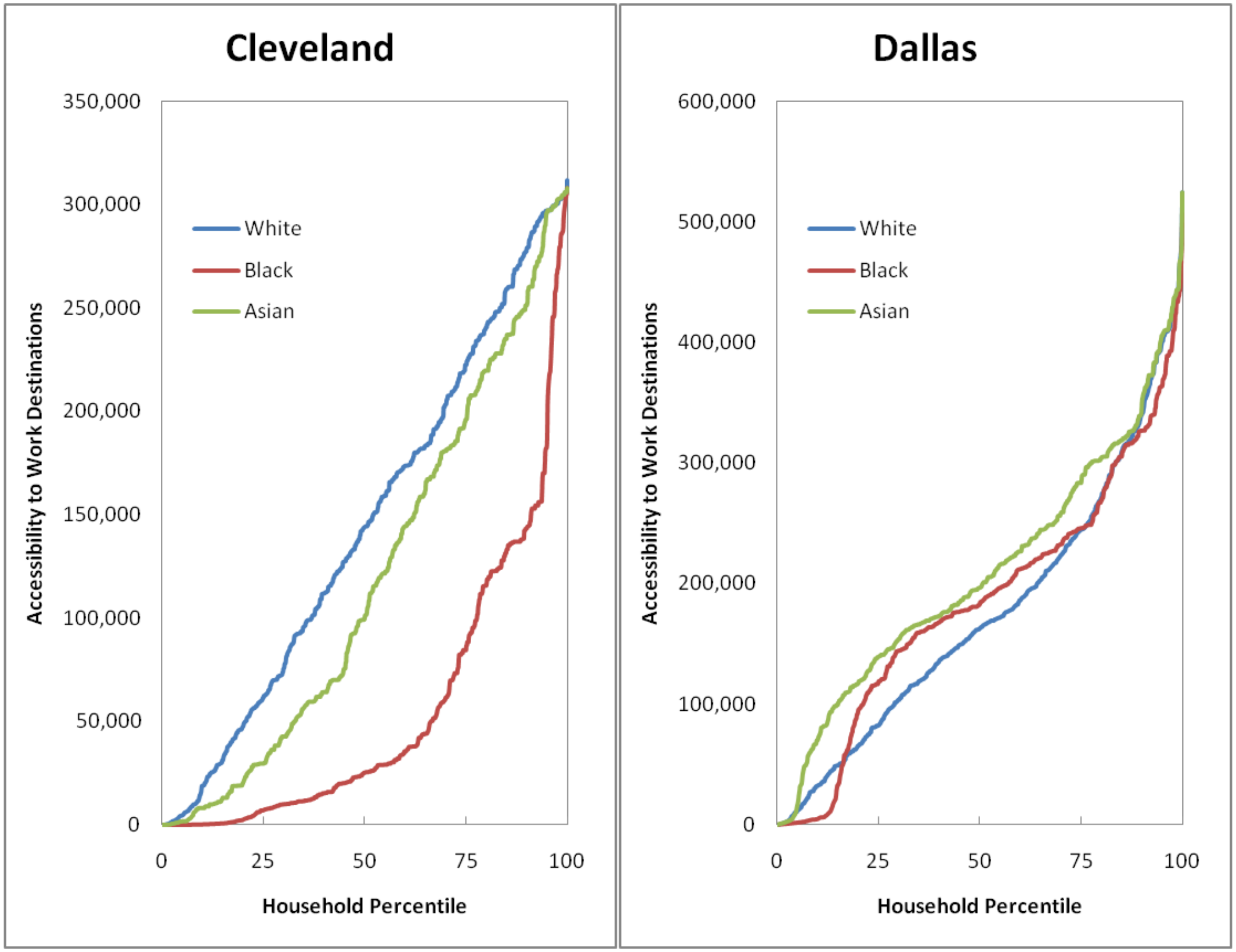

Philadelphia
600,000
500,000
400,000
300,000
200,000
100,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

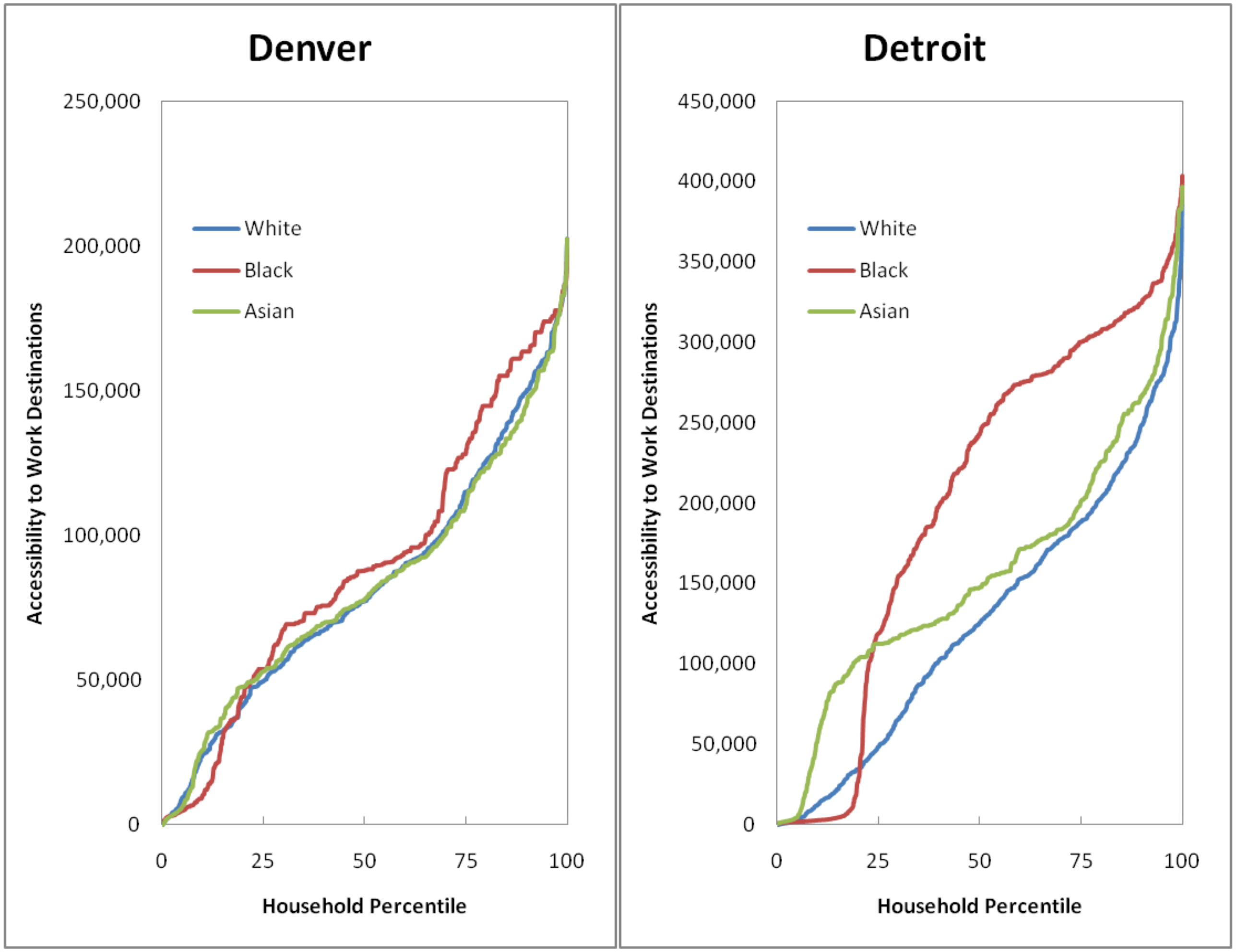

Atlanta
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

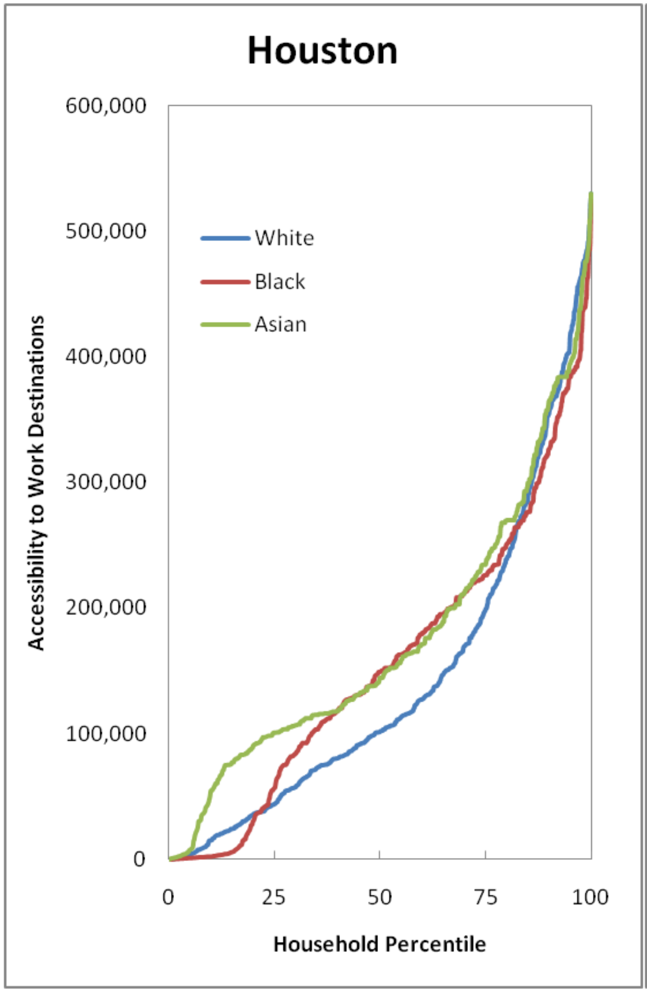

Baltimore
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile


Boston
600,000
500,000
400,000
300,000
200,000
100,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile
Columbus, OH
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

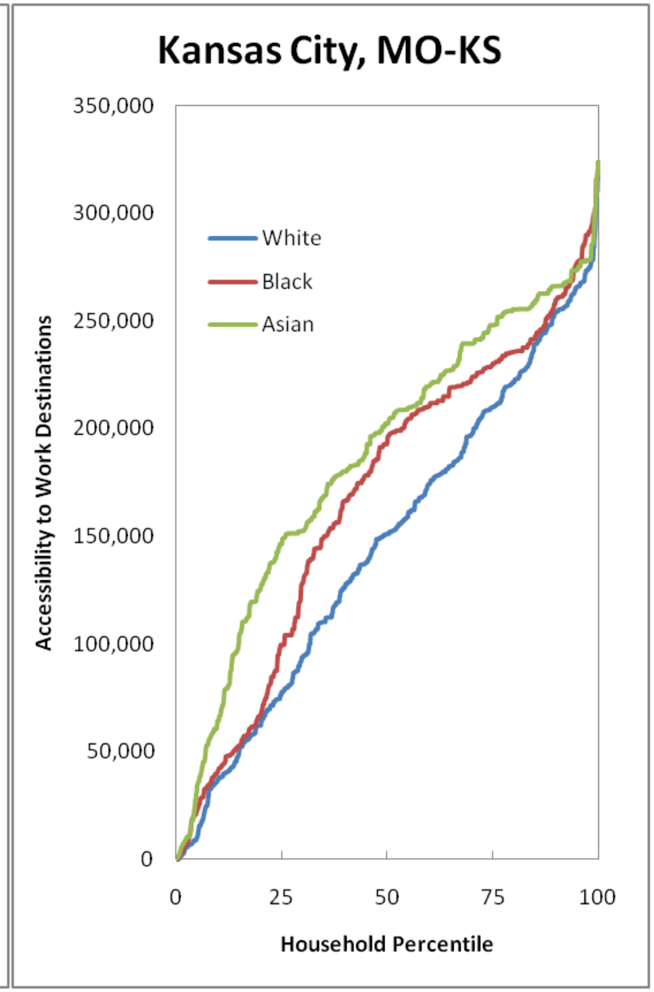

Charlotte
250,000
200,000
150,000
100,000
50,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile
Cincinnati
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile


Cleveland
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile
Dallas
600,000
500,000
400,000
300,000
200,000
100,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

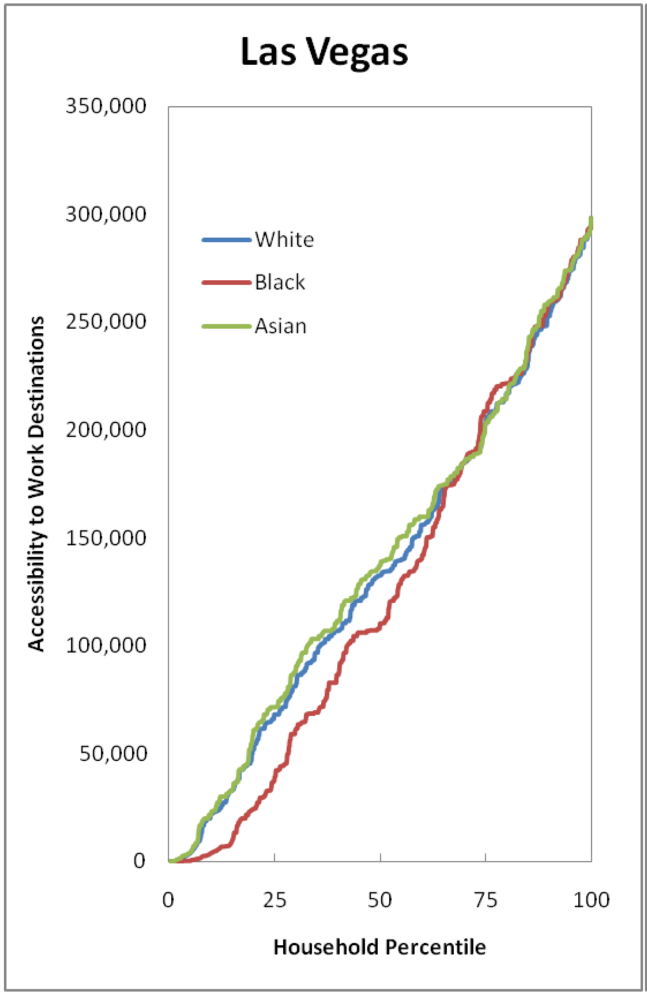

Denver
250,000
200,000
150,000
100,000
50,000
0
0
25
50
75
100
Household Percentile
Accessibility to Work Destinations
White
Black
Asian
Detroit
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0
25
50
75
100
Household Percentile
Accessibility to Work Destinations
White
Black
Asian

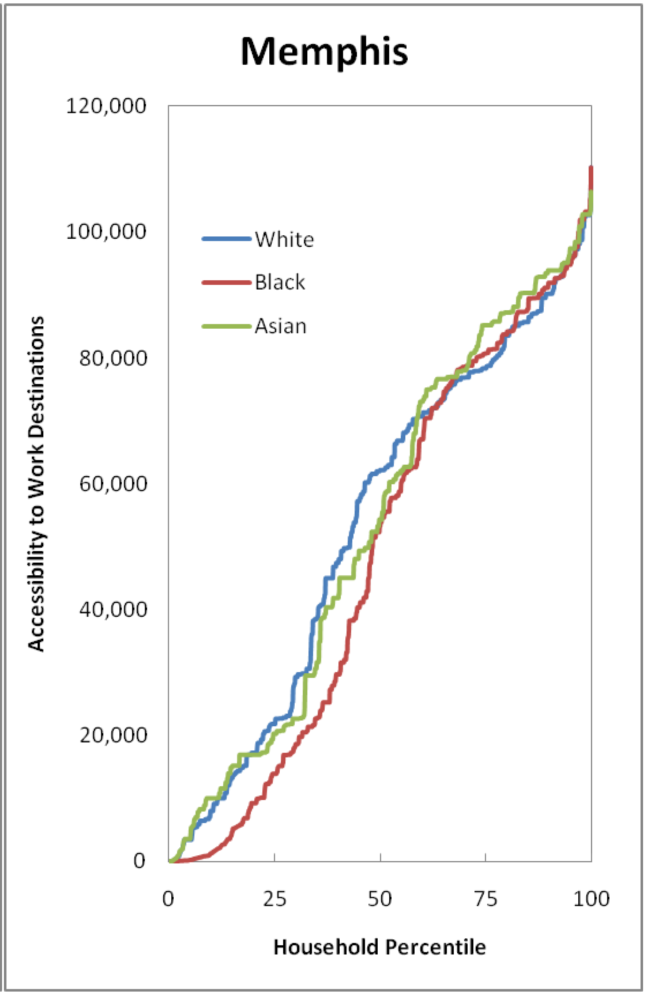


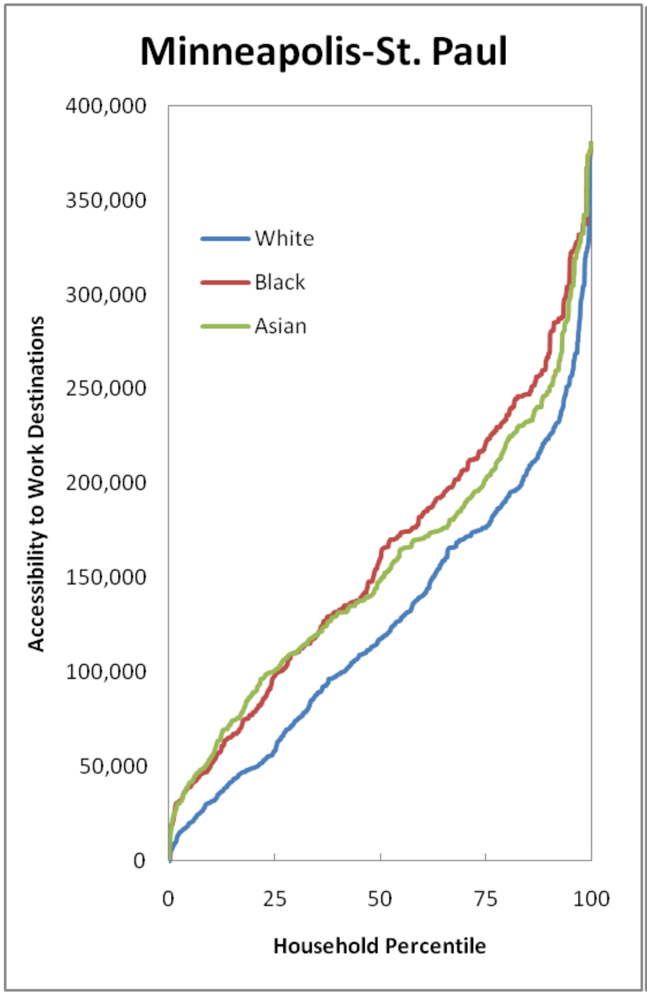
Houston
600,000
500,000
400,000
300,000
200,000
100,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

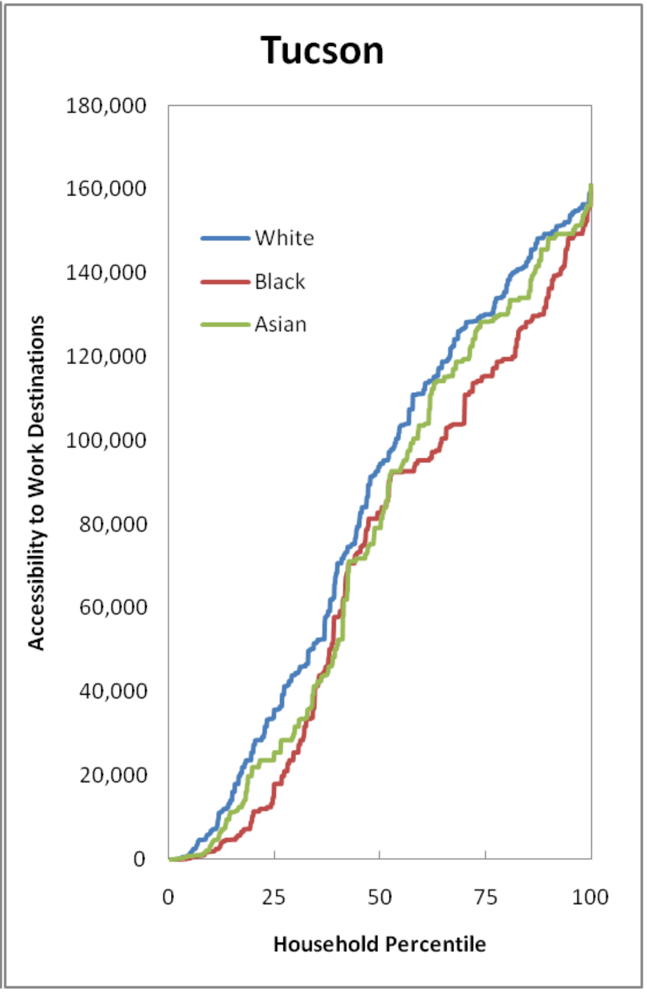


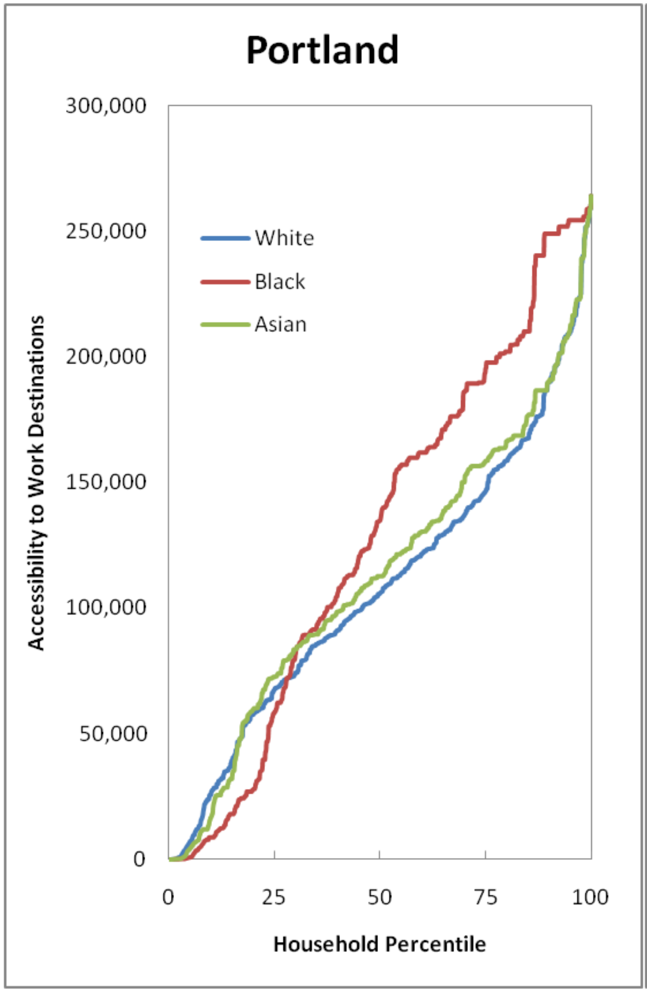
Kansas City, MO-KS
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

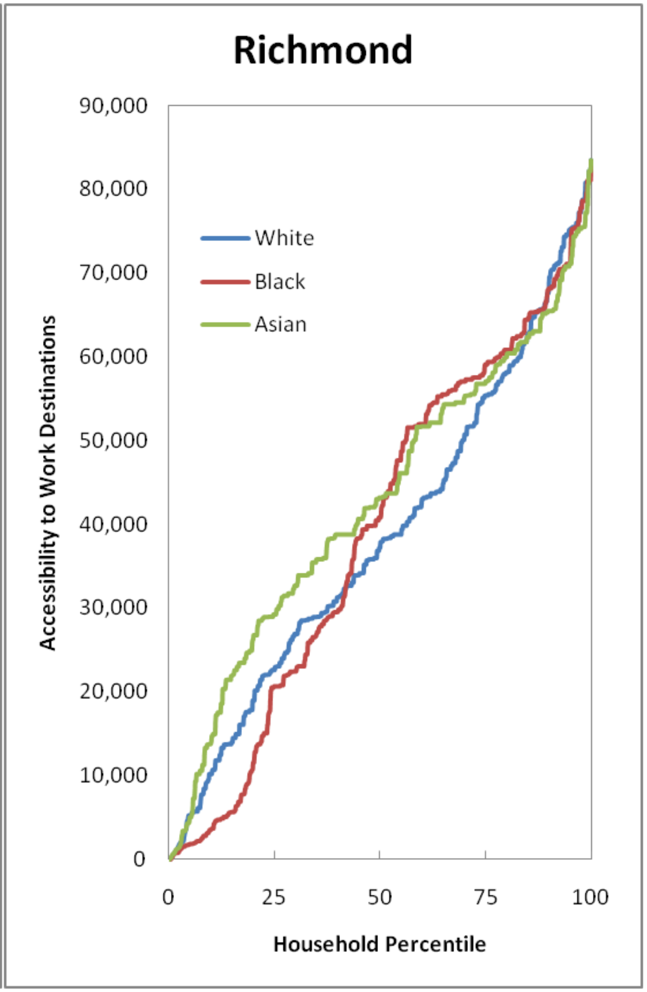

Las Vegas
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
0
25
50
75
100
Accessibility to Work Destinations
Household Percentile
White
Black
Asian

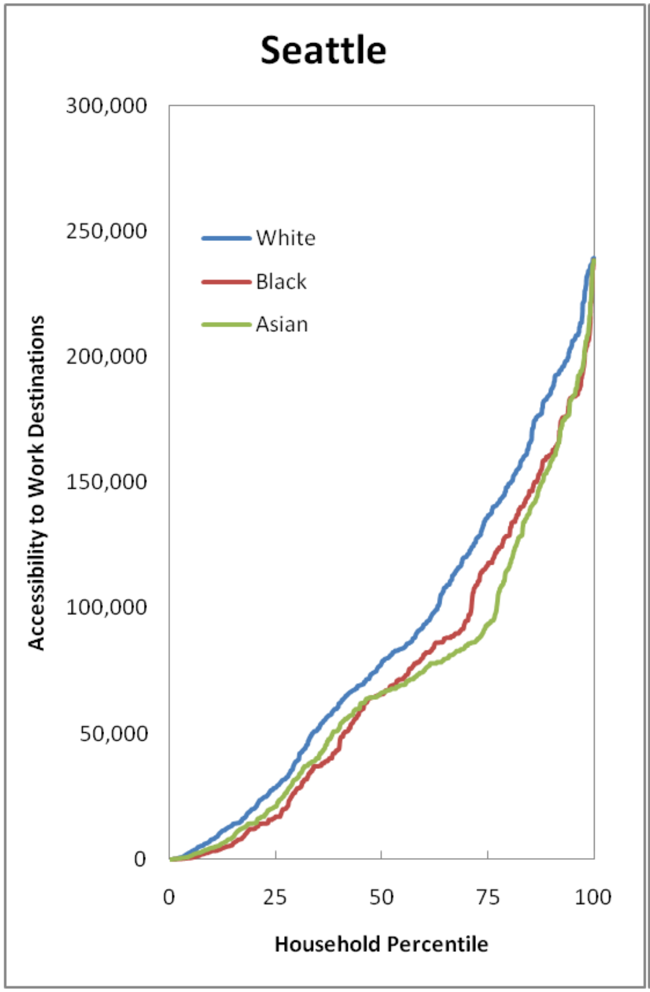

Memphis
120,000
100,000
80,000
60,000
40,000
20,000
0
0
25
50
75
100
Accessibility to Work Destinations
Household Percentile
White
Black
Asian

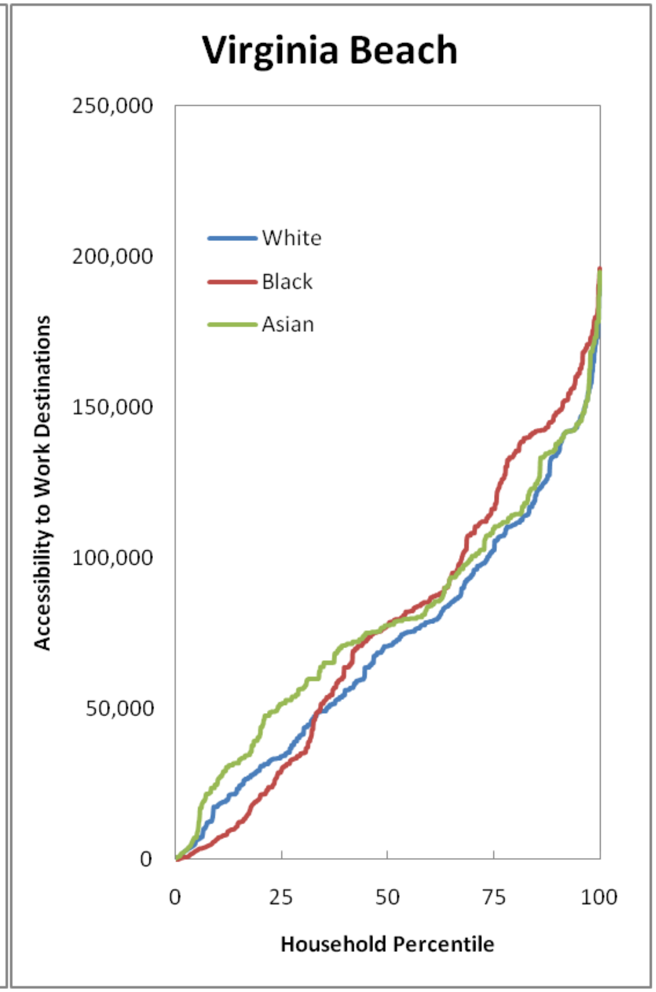

Minneapolis-St. Paul
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile


Tucson
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
White
Black
Asian
Accessibility to Work Destinations
0
25
50
75
100
Household Percentile

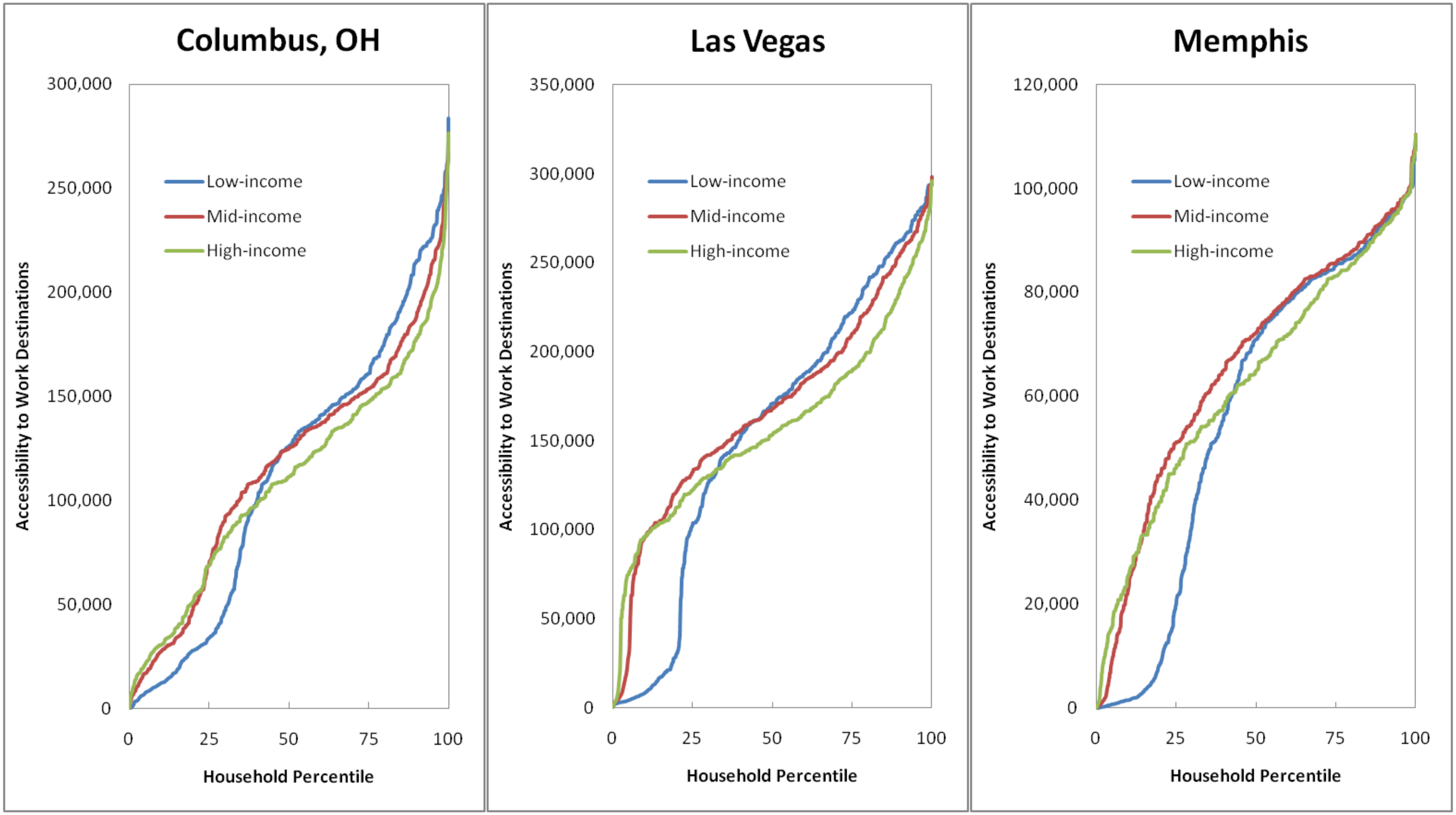

Portland
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

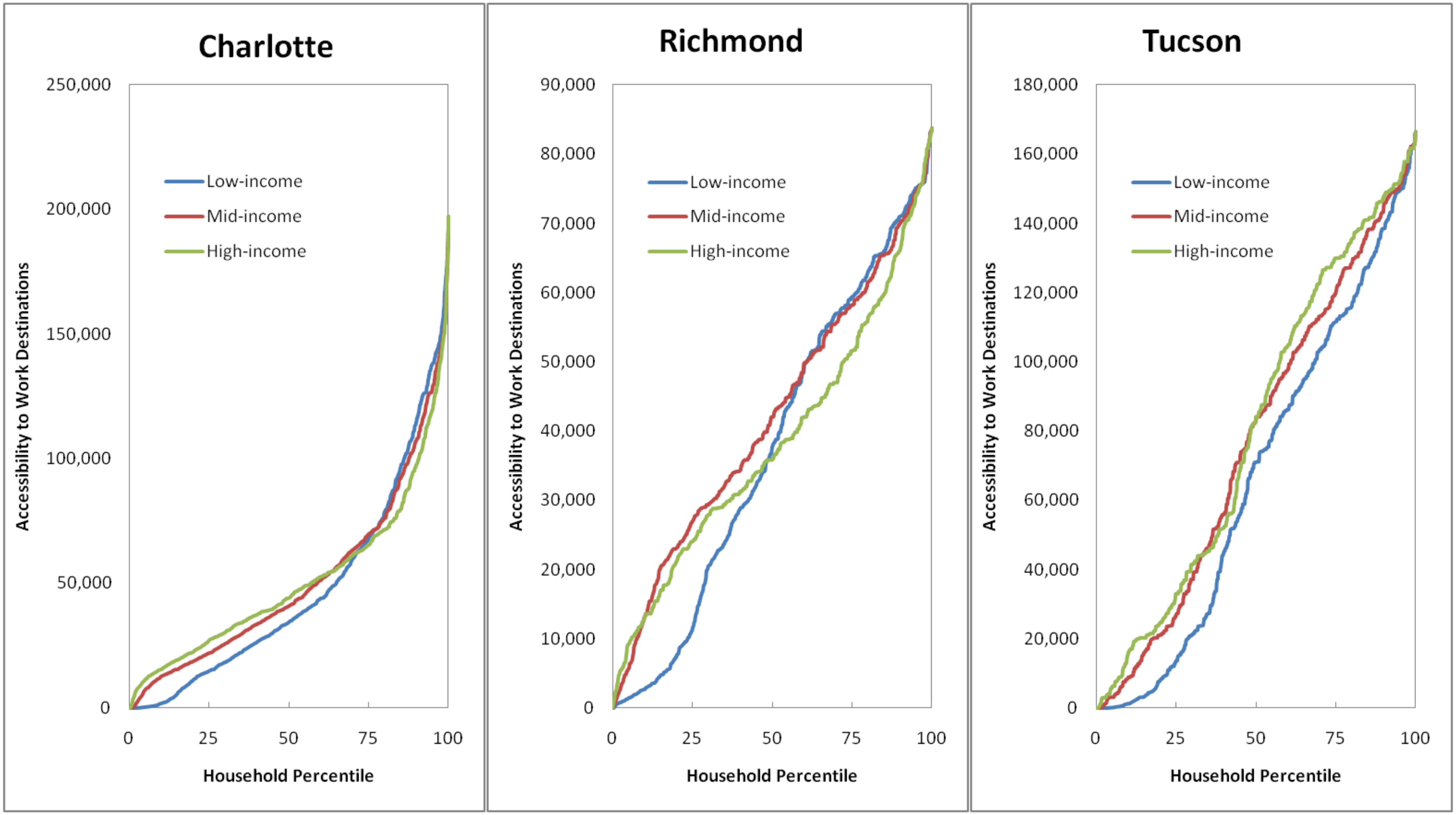

Richmond
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

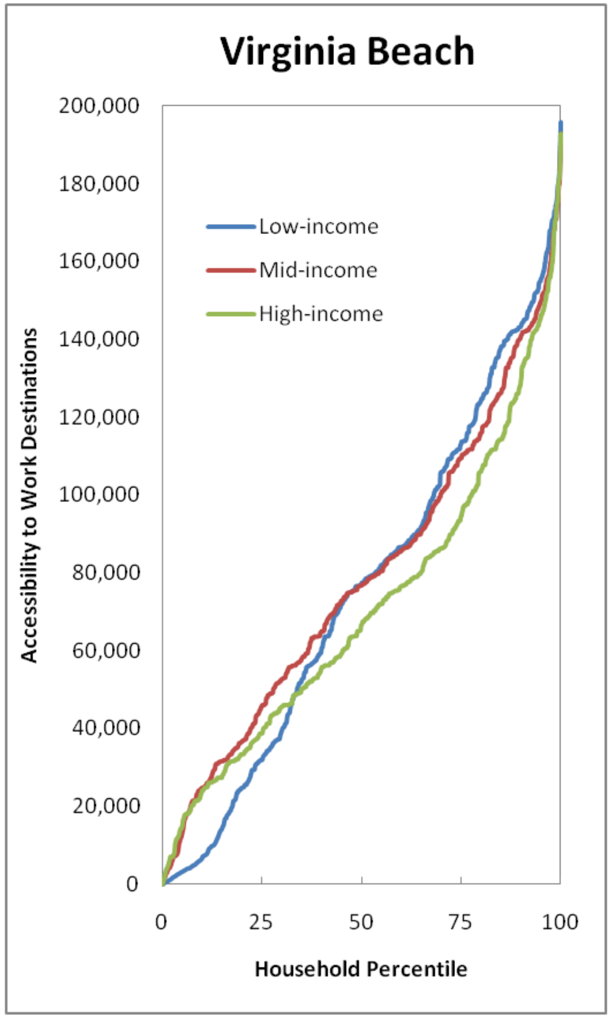

Seattle
300,000
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile


Virginia Beach
250,000
200,000
150,000
100,000
50,000
0
Accessibility to Work Destinations
White
Black
Asian
0
25
50
75
100
Household Percentile

Appendix I: Equity Comparisons of Work Accessibility by Household Income for the 25 Available Metropolitan Regions


Columbus, OH
Las Vegas
Memphis
Low-income
Mid-income
High-income
Accessibility to Work Destinations
Household Percentile
300,000
250,000
200,000
150,000
100,000
50,000
0
350,000
120,000
100,000
80,000
60,000
40,000
20,000
25
50
75
100


Charlotte
Richmond
Tucson
Low-income
Mid-income
High-income
Accessibility to Work Destinations
Household Percentile
250,000
200,000
150,000
100,000
50,000
0
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
25
50
75
100


Virginia Beach
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Accessibility to Work Destinations
Low-income
Mid-income
High-income
0
25
50
75
100
Household Percentile

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