Access to Destinations: Annual Accessibility Measure for the Twin Cities Metropolitan Area

Report #13 in the series

Access to Destinations Study

Report # 2012-34

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16. Abstract (Limit: 250 words)

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Access to Destinations: Annual Accessibility Measure for the Twin Cities Metropolitan Region

Final Report

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Executive Summary

Transportation systems are designed to help people participate in activities distributed between places. A well-functioning transportation system makes it easy for people to reach destinations they value. Accessibility is a measure of the performance of a transportation system in meeting this goal. The Access to Destinations research project, begun in 2006, is a multi-stage investigation into the detailed measurement of accessibility across the Twin Cities metropolitan area. Its goal is to define a practical measurement, and a process for conducting that measurement, that can be implemented on a recurring basis to support planning and performance evaluation of a multi-modal transportation system.

This report summarizes previous phases of the Access to Destinations project and applies the techniques developed over the course of the project to conduct an evaluation of accessibility in the Twin Cities metropolitan region for 2010. It describes a methodology that can be used to implement future evaluations of accessibility, including a discussion of the development and use of software tools created for this evaluation.

The word accessibility has been around in the transportation planning field for more than 40 years, yet one often sees the term misused. It is more comprehensive than mobility, which measures the ease of moving through a transportation network, regardless of destination. Many cities focus on mobility, using congestion levels and annual mobility reports to evaluate the performance of their transportation systems. However, mobility-based evaluation can mislead by looking only at the costs of travel while ignoring the benefits. Access to Destinations researchers have demonstrated the feasibility of measuring accessibility at the metropolitan level and have established and refined new methods for collecting the necessary data describing land use and travel times. Using these methods, they evaluated accessibility in the Twin Cities in 1995, 2000, and 2005. Finally, they applied these techniques to forecasts of population and transportation networks in 2030 to demonstrate the use of accessibility as a metric for evaluating a variety of planning scenarios.

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reasonable expectation of continuity in the future, and that are usable with a minimum of manual processing and technical expertise.

Chapter 1

Introduction

Transportation systems are designed to help people participate in activities distributed between places. A well-functioning transportation system makes it easy for people to reach destinations they value. Accessibility is a measure of the performance of a transportation system in meeting this goal. The Access to Destinations research project, begun in 2006, is a multi-stage investigation into the detailed measurement of accessibility across the Twin Cities metropolitan area. Its goal is to define a practical measurement, and a process for conducting that measurement, that can be implemented on a recurring basis to support planning and performance evaluation of a multi-modal transportation system.

This report summarizes previous phases of the Access to Destinations project and applies the techniques developed over the course of the project to conduct and evaluation of accessibility in the Twin Cities metropolitan region for 2010. It describes a methodology which can be used to implement future evaluations of accessibility, including a discussion of the development and use of software tools created for this evaluation.

Chapter 2

Defining Accessibility

The word accessibility has been around in the transportation planning field for more than 40 years, yet one often sees the term misused. Clarity in definition is important. *Accessibility* measures the ease of reaching valued destinations. It is more comprehensive than *mobility*, which measures the ease of moving through a transportation network, regardless of destination. Many cities focus on mobility, using congestion levels and annual mobility reports to evaluate the performance of their transportation systems [1]. But mobility-based evaluation can mislead by looking only at the costs of travel while ignoring the benefits. [2]

The distinction between accessibility and mobility can be illustrated by comparing Manhattan and Manitoba. Travel in Manhattan is slow in terms of distance that can be covered in a given unit of time, yet a traveller can reach many destinations in a short time. In contrast, speeds on roads in Manitoba are quite high, but the accessibility is lower because there are fewer destinations to reach. Thus, we can say that Manhattan has higher accessibility while Manitoba has higher mobility. [3]

Over the past decades, various theoretical measures of accessibility have been proposed. All of them require as inputs two fundamental types of data: information about origins and destinations, and information about the costs of moving between them. Origins and destinations are locations with specific land use properties. Travel time is a traditional, widely-understood, and easily comparable representation of transportation cost. Throughout the Access to Destinations project, researchers developed methods for collecting and analyzing geographical land use data, as well as for estimating the travel times between locations using a variety of transportation modes.

2.1 Cumulative Opportunities Measure

The most basic of the identified methods of measuring accessibility is to evaluate the *cumulative opportunities* reachable from an origin within a given travel time threshold. This approach begins by specifying a mode and travel time of interest, and then counts the number of opportunities that can be reached via that mode within that travel time. For example, this measure can be used to identify the number of employment opportunities that can be reached within 30 minutes by car from a specific residential location. [3] A typical representation of cumulative opporunities accessibility is provided in Equation A.1. Figure 2.1 demonstrates the display of cumulative opportunities accessibility on a map.

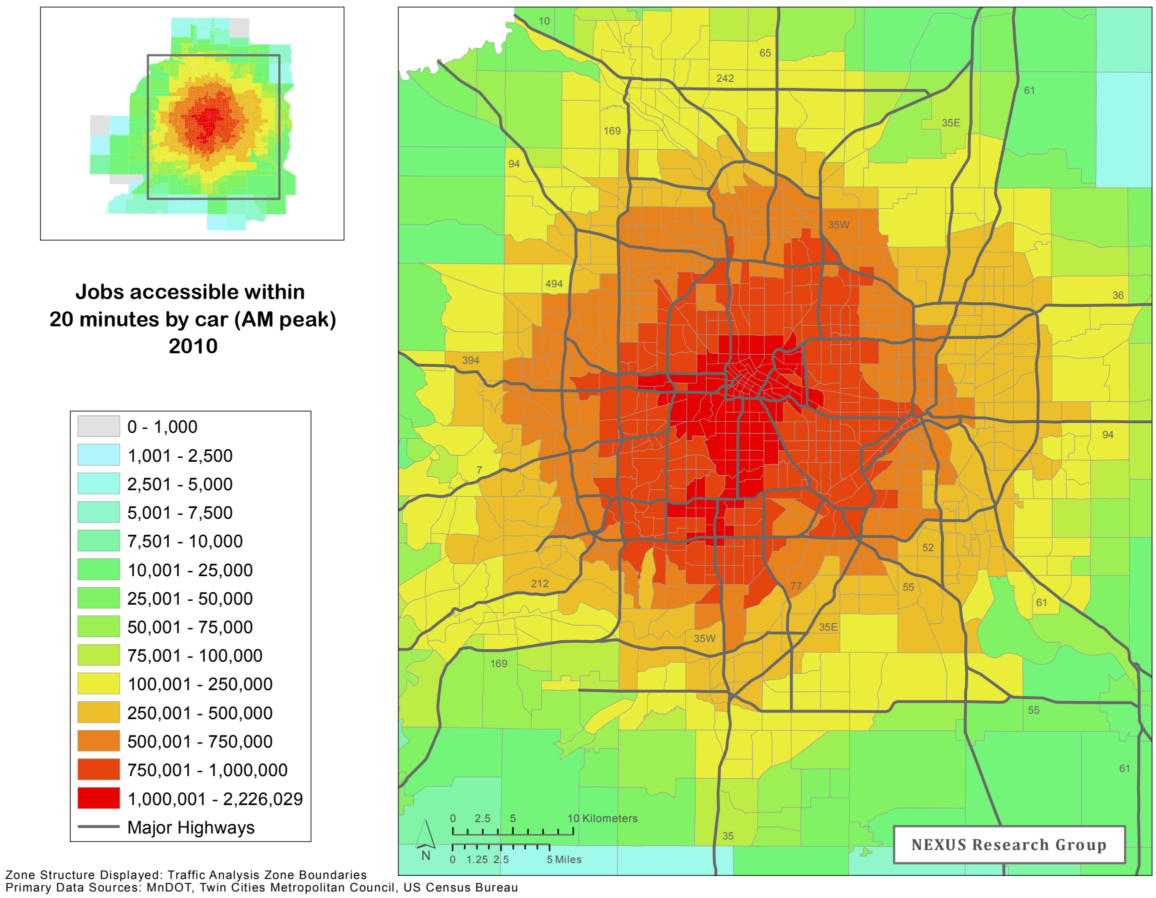

Figure 2.1: Cumulative accessibility to jobs within 20 minutes by auto (2010 AM peak period)

The chief advantage of the cumulative opportunities measure is its simplicity to interpret. Because the final metric is an actual count of reachable destinations, it is easily communicable. Additionally, changes in land use or the transportation system have intuitive effects on cumulative opportunities measures of accessibility. For example, if two new banks open within 10 minutes of a location, that locations cumulative opportunities accessibility to banks will increase by 2.

However, this simplicity also accounts for the main disadvantages of the cumulative opportunities measure. The binary nature of the measure creates artificial distinctions between destinations that may have almost equivalent access costs. For example, in a 30-minute accessibility analysis a destination 29 minutes away would be counted while a destination 31 minutes away would be completely excluded.

Also, the measures reliance on travel time thresholds increases the amount of data points and illustrations required to convey a comprehensive assessment of accessibility. Publishing figures and maps which show 30-minute cumulative employment opportunities over- and under-represents the accessibility experienced by individuals who can afford only 20 minutes, or up to 40 minutes, of travel time. Data for additional travel time thresholds can be published, but reaching a balance between concision and a comprehensive representation of accessibility requires trade-offs.

2.2 Weighted Opportunities / Gravity-Based Measure

The cumulative opportunities measure includes only those destinations which meet a specified travel time threshold. Each destination counts either completely or not at all to the metric. In contrast, a *weighted opportunities* measure includes all possible destinations, but weights the contribution of each destination. A destinations weight is determined by a mathematical function of the travel time required to reach it. In many classic studies of accessibility, that function is analogous to Newtons law of gravitational attraction: the weight of each destination is inversely proportional to the square of the travel time required to reach it. This approach to weighting is commonly known as *gravity-based* measure. [3] The map in Figure 2.2 demonstrates this method of measuring accessibility.

Though traditional, a gravity-based weighting is not necessarily the best. A substantial body of research suggests that a negative exponential weighting function is a more accurate representation of the way individuals willingness to travel decreases as travel time increases. [3] The map in Figure 2.3 illustrates weighted accessibility using a negative exponential weighting method.

However, this approach requires choosing an exponential coefficient to use in the weighting function, and this choice is not straightforward. Access to Destinations researchers used survey data to estimate the most appropriate exponential coefficients and found that they vary significantly with both mode and trip purpose. For example, individuals willingness to travel decreases more rapidly with distance when walking than when travelling by car. Individuals are also more willing to travel farther when heading to work than when travelling to shop. [4]

Equations A.2 and A.3 demonstrate typical formulations of weighted opportunities accessibility. The need to choose the most appropriate weighting function and coefficients adds complexity to the calculation of an accessibility measure based on weighted opportunities. This complexity also makes the resulting measure more difficult to communicate and interpret. Because the contribution of each destination is weighted by travel time, the final metric can not be interpreted as a simple count of destinations. If destinations are generally far away, the actual number of destinations might be far greater than the sum of their weighted contributions. [3, 4]

Despite these complexities, a weighted opportunities measure of accessibility has distinct advantages. Most importantly, it provides a representation of accessibility that corresponds closely to observed traveller behavior. This accuracy is further enhanced when using expo-

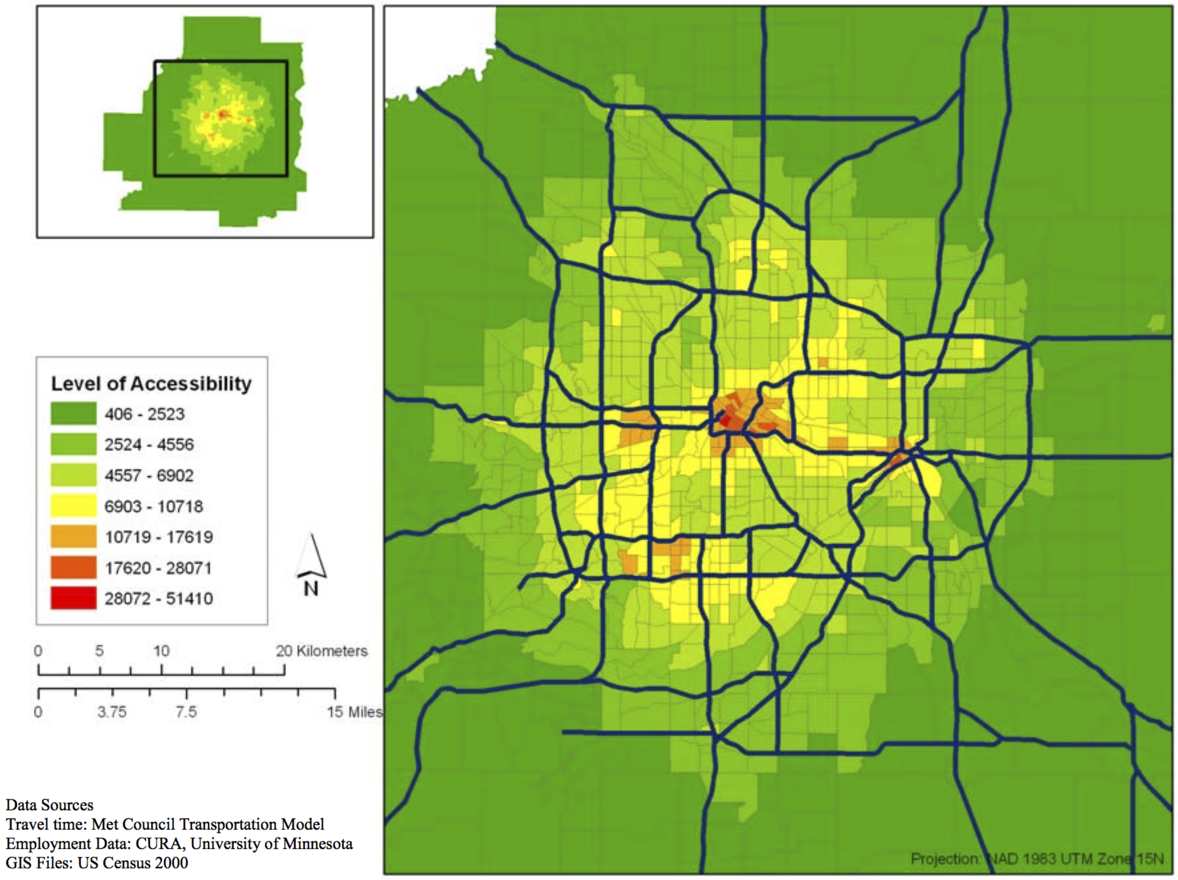

Figure 2.2: Inverse-square (gravity) weighted accessibility to jobs (2000)

nential coefficients that are calibrated for specific modes and trip purposes.

Also, because a weighted opportunity measure includes contributions from all possible destinations, comprehensive accessibility across all travel times from a single origin can be represented by a single index, and comprehensive regional accessibility can be represented on a single map. In contrast, the cumulative opportunities measure requires individual indices and maps for each travel time threshold of interest.

2.3 Other Measures

Researchers also investigated other potential measures of accessibility, including measures based on utility and time constraints. In general, though these remain interesting avenues of research, their complexity and data intensity make them unsuitable for practical implementation.

A *utility-based* measure of accessibility is theoretically very promising because it adheres to theories of travel behavior. Cumulative opportunities and weighted opportunities measures of accessibility do not account for differences in preferences among individualsthey

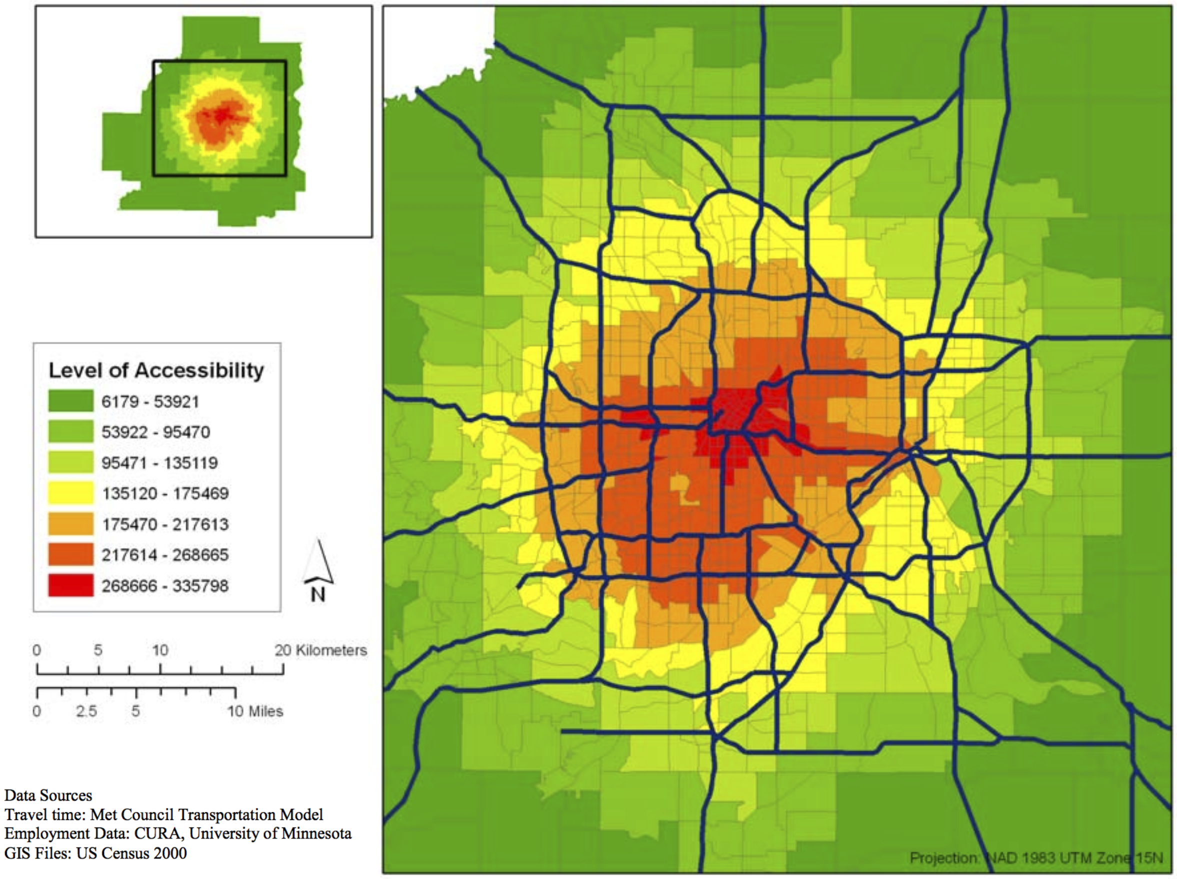

Figure 2.3: Negative exponential weighted accessibility to jobs (2000)

imply that all people living in the same analysis zone will experience the same level of accessibility. In reality, individuals have different criteria for evaluating potential destinations, and destinations satisfy these criteria to varying degrees. For example, one person might evaluate grocery stores primarily based on price, while another might base his decision on availability of a particular brand. Due to their distinct preferences, these people will derive different levels of utility from the same grocery stores. Utility-based measures of accessibility seek to quantify and incorporate these differences in destination utility. While this approach has advantages, the complexity and cost of evaluating traveller preferences and destination utilities make its implementation at the metropolitan level unrealistic. [3]

Constraints-based measures of accessibility recognize that people do not have an unlimited amount of time available for travel in a day, and that most people have a set of mandatory activities—most notably, work—that take place at specific times and locations. These times and locations impose constraints on what other destinations a traveller is able to reach during a day. Applying these constraints to a measure of accessibility may give a more accurate picture of an individuals ability to reach destinations. However, the need for detailed schedule and location information from individuals makes constraints-based measures of accessibility unsuitable for large-scale implementation. [3]

Chapter 3

Using Accessibility Metrics

3.1 Comparing and Summarizing Accessibility

The Access to Destinations project has focused on creating measures of accessibility that use small geographical areas—TAZs and Census blocks—as the unit of analysis. While it is interesting to know that from a certain TAZ it is possible to reach 100,000 employment opportunities within 10 minutes, this fact alone has little power to drive planning or enable performance evaluation. To fulfill this function, it is necessary to answer two questions. First, how does this areas accessibility compare to the accessibility of other areas? Second, how has this areas accessibility changed over time? In short, we must be able to compare accessibility across space and across time.

3.1.1 Across Space

Accessibility based on cumulative opportunities is directly comparable across space. Because the cumulative opportunities measure is a simple count of destinations reachable in a given travel time threshold, its value corresponds directly to the number of destinations. If research shows that area A has 30-minute accessibility to 100,000 employment opportunities and area B has 30-minute accessibility to 200,000 employment opportunities, the implications are clear: residents in area B can access twice as many potential jobs with 30 minutes than residents in area A.

Comparisons based on weighted opportunities measures of accessibility are less intuitive. A weighted opportunities measure is based on both the number of destinations and travel times, but does not directly represent either. If research shows that area A has an accessibility level of 9,000 and area B has an accessibility level of 3,000, it is possible only to conclude that area A has higher accessibility than area B.

Normalization can improve the ease and understandability of comparing accessibility measures across space. A common goal is to identify areas which have high or low accessibility relative to the general accessibility of a parent region. For example, construction of a new transportation facility generally increases accessibility for the region as a whole, but sub-regions experience varying changes in accessibility based on their location relative to the new facility. It is often necessary to identify which sub-regions benefit the most from new transportation facilities. To facilitate this measurement, the accessibility of each sub-region can be normalized by dividing it by the general accessibility of the parent region. Effectively, this measures how equitably accessibility is distributed across the region. [3]

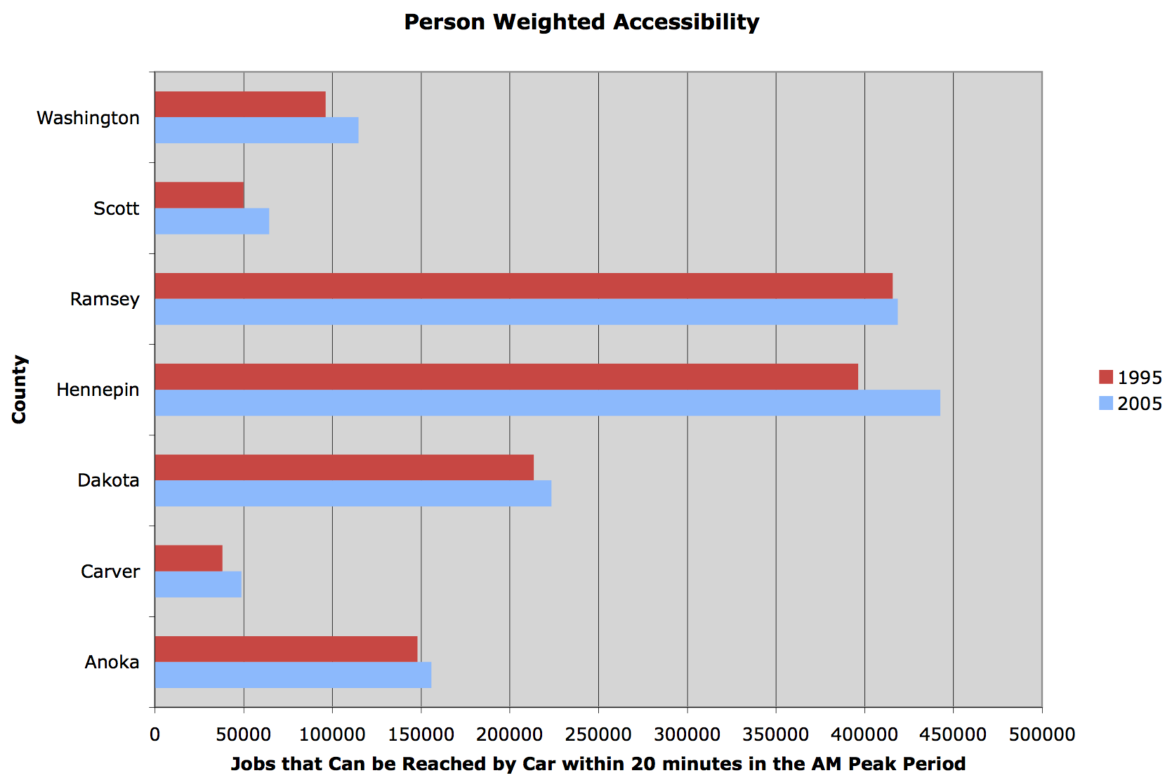

Figure 3.1: Person-weighted accessibility to jobs by county (1995–2005)

While the Access to Destinations project has focused on analysis at the TAZ and Census block level, in planning and policy contexts it is often necessary to make comparisons at higher levels of geography. For example, policymakers may be interested in the relative accessibility experienced by residents of Minneapolis and Saint Paul. To facilitate such a comparison, it must be possible to aggregate accessibility measures. A simple approach would be to average the accessibility of all sub-regions—in this case, of all the TAZs in Minneapolis—to determine the accessibility of the parent region. However, this is appropriate only if the population is evenly distributed across all sub-regions. If a TAZ in Minneapolis has very high accessibility but a very low population, it does not contribute significantly to the accessibility experienced by Minneapolis residents on average. The contribution of each TAZ to overall accessibility should be weighted by its population. To facilitate these types of comparisons, Access to Destinations researchers proposed *person-weighted* accessibility: a weighted average of accessibility by zone, where the weight is the population in that zone experiencing that level of accessibility (Equation A.4). [5] Figure 3.1 demonstrates the possibility of using person-weighted accessibility to compare job accessibility across counties in the Twin Cities metropolitan area.

3.1.2 Across Time

Accessibility rarely remains constant. As cities evolve over time, changes in land use and in the transportation system are reflected by changes in accessibility. Because of their generally high public capital costs, it is especially important that we are able to measure the changes in accessibility brought about by transportation infrastructure projects. We must be able to generate measurements of accessibility for various points in time and draw meaningful conclusions from their comparison.

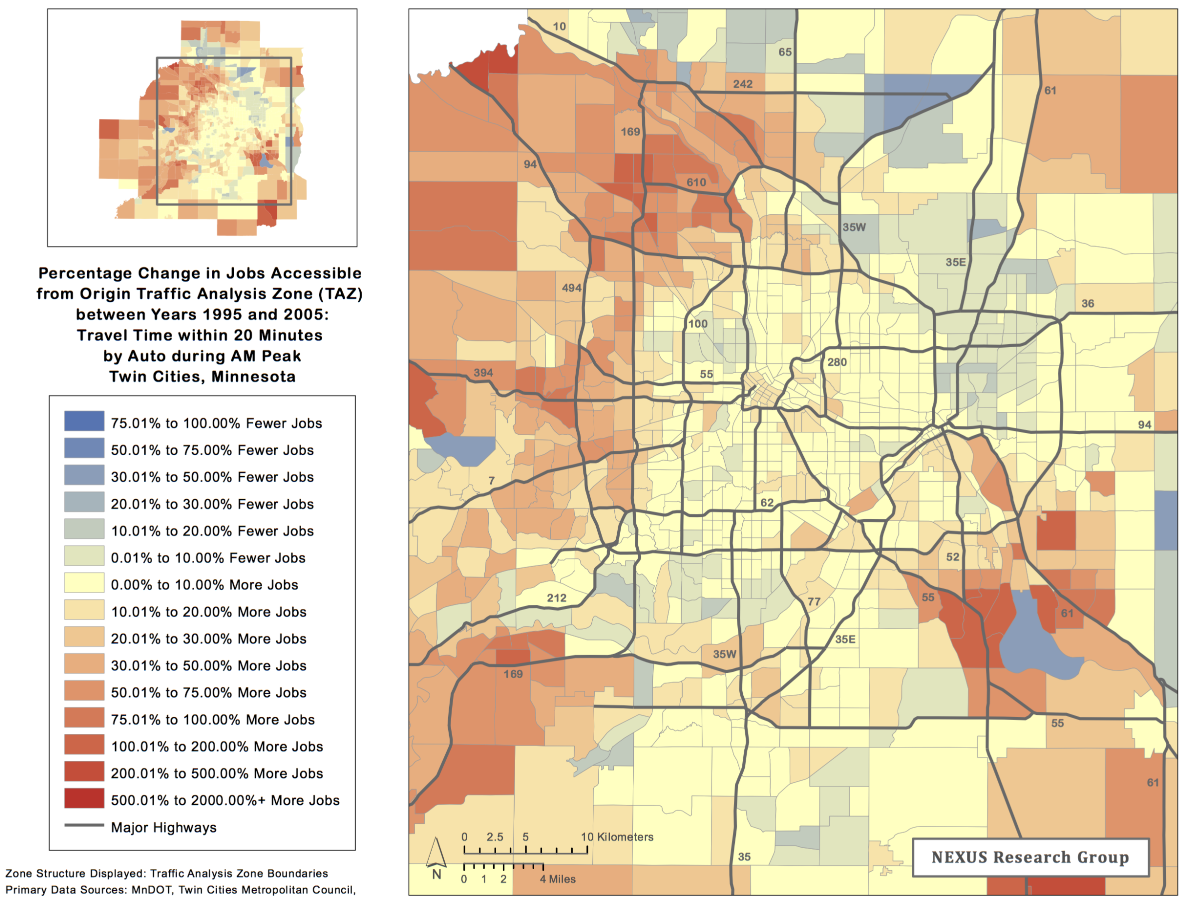

Figure 3.2: Percent change in number of jobs accessible in 20 minutes by car (1995–2005)

When measuring historical accessibility, data collection is often a challenge. Historical data is not always available, and when it is available it may not be analogous to current data. Access to Destinations researchers encountered these types of challenges and, where possible, developed methods for overcoming them. For example, estimation of historical travel times on the freeway system revealed significant amounts of missing data. These gaps could be filled in by identifying spatial and temporal patterns in the remaining data. In other cases, a lack of historical data made measurement of accessibility less accurate. Historical signal timing data was particularly difficult to acquire. Access to Destinations researchers made recommendations for collecting and cataloging this type of information to ensure that it is available for future analysis.

Once the necessary data is available and accessibility is measured, it is possible to build an understanding of how accessibility changes over time. Accessibility measurements at various points in time can be combined to compute the percentage change in accessibility, as illustrated in Figure 3.2. It is important, however, that the same measure of accessibility is used at all time points of interest. For example, to compare current accessibility with cumulative opportunities accessibility in 2000, current accessibility must be evaluated using the same cumulative opportunities measure. Therefore, adoption of a specific measure of accessibility should be carefully considered, and that measure should remain consistent in the future. [2]

3.1.3 Across Modes

The various measures of accessibility described above all deal with the accessibility provided by a single transportation mode. Currently, a multi-modal accessibility analysis generates separate accessibility measures for each mode. For example, using cumulative opportunities, research might show that an area has 30-minute accessibility to 100,000 employment opportunities by automobile, 25,000 by transit, 25,000 by cycling, and 5,000 by walking.

These separate measures provide a simple, quick, and intuitive way of comparing the accessibility provided by different modes. As long as the modes are relatively few and their unique characteristics are well-understood, direct modal comparisons would likely be easy to communicate in a public or political context. As when comparing across time and space, it is important that the same measure of accessibility is used of all modes of interest. In the case of a cumulative opportunities measure, this implies using a consistent time threshold for comparison between modes.

While comparisons between modes are relatively straightforward, summarizing accessibility across modes is an unresolved challenge. Access to Destinations research describes candidate methods for combining these into a single accessibility measure, involving adding accessibility across modes and/or weighting by mode share, but each has disadvantages.

The simplest approach would be to sum the accessibility provided by each mode to arrive at a representation of total accessibility (Equation A.5). However, since any individual trip can only be made by a single mode, this overstates total accessibility by failing to account for actual mode choices. Also, accessibility could be inflated by introducing a new mode—even if that mode was rarely used or was substantially similar to existing modes. Weighting the accessibility contributed by each mode by that modes share of the travel market (Equation A.6) helps correct these problems, but because mode share depends on travel cost, this approach weights those costs doubly. [3] It is possible to avoid this double-weighting by using general mode share at the origin rather than the mode share of origin-destination pairs, but this ignores the fact that mode choice is based on the trip, not just the origin. [3]

Weighting by mode share has disadvantages when comparing accessibility over time. Changes in the accessibility provided by a single mode also influence mode share for all modes, and this can produce counterintuitive results. For example, consider a region where accessibility to jobs by auto is 100,000 and accessibility by transit is 25,000; the automobile mode share is 90% and the transit mode share is 10%. Using a mode share-weighted measurement, total accessibility is $(100,000 \times 0.9) + (25,000 \times 0.1) = 92,500$. If transit accessibility doubles, it is reasonable to expect the mode share of transit to increase as that mode becomes more attractive. This results in a corresponding decrease in the automobile mode share. If transit mode share doubles to 20% and automobile mode share decreases to 80%, then total accessibility is now $(100,000 \times 0.8) + (25,000 \times 0.2) = 90,000$. It appears that overall accessibility has *decreased* due to an increase in the accessibility offered by a single mode. This counterintuitive result can be avoided by keeping mode share fixed when comparing mode share-weighted accessibility across time, but doing so ignores the ways in which changes in accessibility influence travel behavior.

3.1.4 Relative Accessibility

It is also to directly indicate the relationship between two types of accessibility. For example, a study of transit ridership might be strengthened by examining the ratio of an areas accessibility to jobs by transit to its accessibility to jobs by car. This ratio illustrates the modal balance of accessibility in the area. The same approach can be applied to measures of accessibility to different types of destinations. For example, land use planners might determine an areas suitability for various uses based on the ratio of its accessibility to jobs to its accessibility to resident workers. Figure 3.3 demonstrates this approach. It is simple to create these ratios once the appropriate types of accessibility have been measured. However, care must be taken to ensure that the types of accessibility to be compared are measured using the same method (cumulative opportunities, weighted opportunities, etc.).

3.2 Communicating and Illustrating Accessibility

As discussed above, most measures of accessibility are readily illustrated through maps. However, some measures require a sequence of maps to convey a full sense of accessibility at different time scales. A multi-modal analysis further increases the number of maps required.

The Internet offers an opportunity to create richer and more interactive illustrations of accessibility. Access to Destinations researchers created a web site hosting an interactive database of accessibility in the Twin Cities region (`http://a2d.umn.edu`). The site provides two basic ways to interact with accessibility information for 1995, 2000, and 2005. Simply by clicking on a map, users can query a pre-calculated accessibility matrix showing a selected locations cumulative opportunities accessibility to jobs, major retail stores, restaurants, and several other types of destination. Separate accessibility measures are provided for transit,

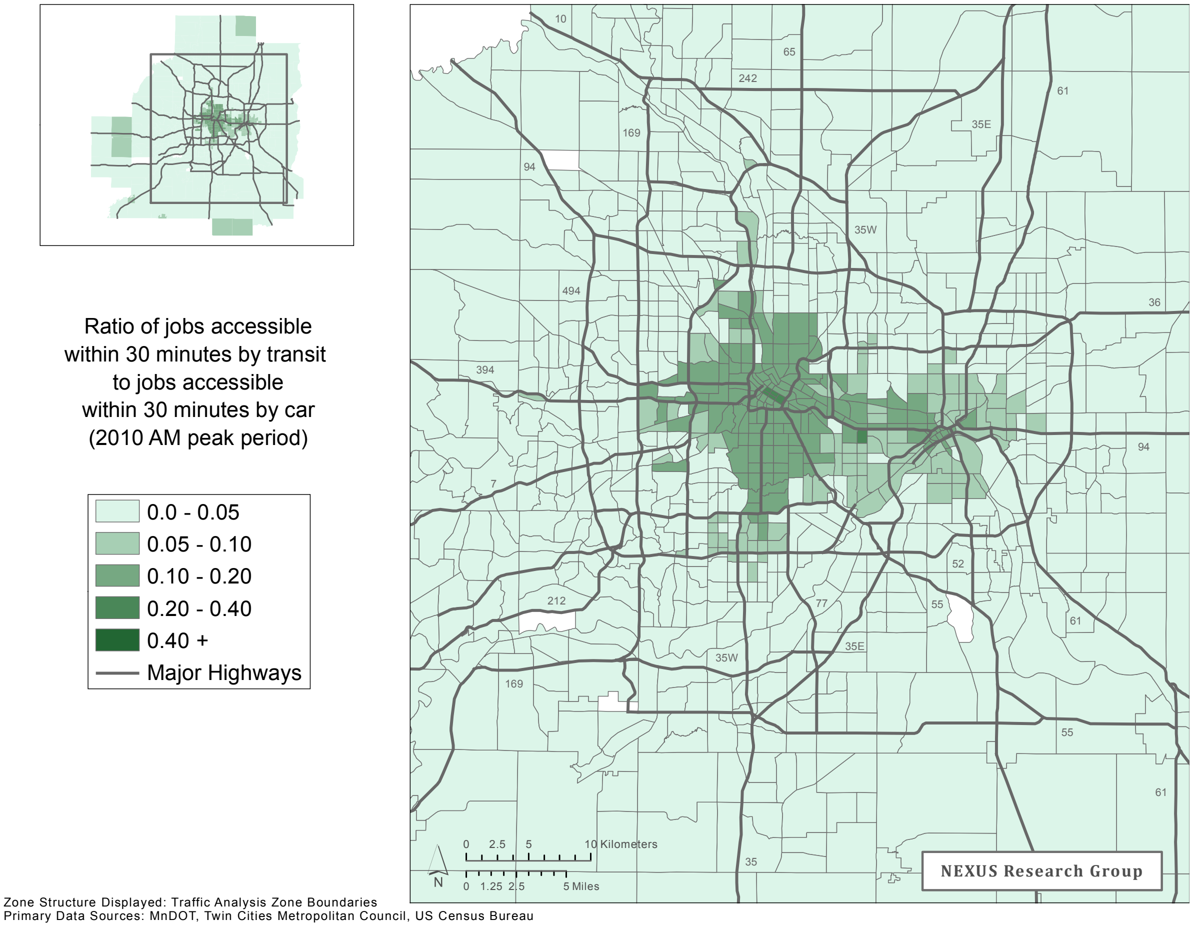

Figure 3.3: Ratio of 30-minute job accessibility by transit to 30-minute job accessibility by auto (2010 AM peak period)

cycling, walking, and driving. Users can also investigate accessibility across the region by selecting a mode, a type of destination, and a travel time threshold to generate a map illustrating the cumulative opportunities accessibility for all areas in the region. [5]

Chapter 4

2010 Accessibility Evaluation

4.1 Overview

This section summarizes the process of evaluating accessibility in 2010 as well as the results. The goal of this evaluation is twofold: it seeks both to generate an accurate representation of accessibility in 2010, and to identify and audit data sources, methods, and metrics that can be used in future evaluations. The current focus on establishing replicable data sources and methodology in some cases recommends or requires changes from those used in previous Access to Destinations research. This section discusses the motivations for these changes as well as the proposed solutions and alternatives. Additionally, it describes the development and use of software tools created for this evaluation which are designed from the ground up to facilitate easily-replicable evaluations of accessibility. Detailed instructions for using these tools can be found in the Appendices.

4.2 Data

Ideal data sources for an evaluation of accessibility in 2010 will fit four criteria:

1. They should provide a **good representation of actual conditions** for the entire year of 2010.

2. They should be **based on measurements** whenever possible, rather than on models, predictions, or forecasts.

   Since our goal is to *evaluate* accessibility rather than forecast or predict it, data sources based on measurements are strongly preferred over those based on models.

3. They should provide a **reasonable expectation of continuity** in the future.

   Since this accessibility evaluation is designed to be implemented on an annual or biannual basis, it is important to identify data sources which will be available in a comparable form for the foreseeable future.

4. Finally, they should be usable with a **minimum of manual processing and technical expertise** required.

In many cases it is difficult for a single data source to fully satisfy all of these criteria. The 2010 U.S. Census is a simple example: while it provides an excellent representation of population during 2010, a measurement with comparable methodology will not be available again until 2020. For each category of data described below, the tradeoffs associated with each chosen data source are discussed.

4.2.1 Land Use

Population

Data describing the distribution of population in the Twin Cities metropolitan area are drawn from the 2010 Census. The Metropolitan Council provides a TAZ-level summary of demographic information from the 2010 Census. However, the use of Census population figures comes with a distinct drawback: a population measurement with comparable methodology will not be available again until 2020. For years between decennial Censuses, population estimates from the American Community Survey (ACS) or other sources may be useful.

Labor and Employment

Data describing the distribution of labor and employment in the region are drawn from the U.S. Census Bureaus Longitudinal Employer-Household Dynamics program (LEHD). The workplace area characteristic (WAC) and residence area characteristic (RAC) datasets provide, respectively, Census block-level counts of employee work locations and home locations.

In general, LEHD is a very useful data source for accessibility evaluation because it is updated yearly and is drawn from actual payroll records collected at the state level—in this case, by the Minnesota Department of Employment and Economic Development (DEED). However, two important considerations must be kept in mind. First and most importantly, LEHD data is *synthetic*: while it is based on actual payroll records, the published results are created by an algorithm designed to produce data which are *statistically similar* to the underlying data, and which converge to the same distribution when aggregated to the Census tract level and higher. [6]

Second, the creation of LEHD datasets can involve considerable delay. For example, LEHD data covering 2010 were not released until April 27, 2012—16 months after the end of 2010. LEHD data releases for earlier years involved similar waiting periods, which should be anticipated when scheduling cycles for accessibility evaluations.

Commercial Locations

Earlier phases of the Access to Destinations project used datasets purchased from the business research company Dun & Bradstreet, Inc. to determine commercial locations in the region. Similar datasets are available from other vendors. These datasets are generally comprehensive but have two distinct disadvantages. First, they are compiled from a potentially wide variety of public and private data sources using a proprietary methodology. This can pose challenges for ensuring comparability among accessibility evaluations over time. Second, access to these datasets must be purchased annually. [7]

As a potential alternative, Access to Destinations researchers worked with DEED to create a similar dataset drawn entirely from public data sources. This dataset is drawn from the same underlying sources as the Quarterly Census of Employment and Wages (QCEW) and provides a count of firms by NAICS code at the Census block level. It is available for little or no cost, and, as part of a national program overseen by the U.S. Bureau of Labor Statistics, carries an expectation of methodological stability. However, an important drawback of this dataset is its coverage: for 2010 it identifies roughly half as many firms in the Twin Cities metro area as the Dun & Bradstreet dataset identified for 2005. A comprehensive comparison of these datasets would provide useful guidance.

4.2.2 Travel Time

Auto

Automobiles travel across the network of public roads and highways. Calculating travel times through this network requires two types of information: data describing the structure of the network, and data describing the cost of travel along individual links in the networks. Earlier Access to Destinations projects generally chose data sources for auto travel times based primarily on representational accuracy. This approach produced results which are theoretically very accurate, but also introduced significant complexity and challenges to reproducibility. [5]

For example, in “Access to Destinations, Phase 3: Measuring Accessibility by Automobile [5] researchers drew speeds for individual network links from a total of twelve separate sources (Table 4.1). The decisions and heuristics used to assign sources to individual links are sound, but involved careful evaluation of year-by-year data availability, detailed record-keeping, and in some cases significant computational complexity. In addition, this earlier work employed both *measured* data sources and *modeled* data sources. For these reasons, some of the data sources for auto travel times used in these earlier studies of accessibility are not ideal for implementation in ongoing accessibility evaluation. The following discussion identifies those cases and proposes more replicable alternatives.

Network Structure

The structure of the regional road network is described in detail by the Metropolitan Councils regional planning model network, which has been employed in earlier Access to Destinations research. It provides a network topography for freeway, arterial, and collector roadways in the region.

Table 4.1: Auto travel time data sources used in calculating 2005 accessibility

Data source	Total length of links using data source (km)	Percentage of total network length	AM peak definition	PM peak definition
SUE model (arterial)	8,285	51.04%	6:30–7:30	3:30–4:30
Centroid connector default speed	4,005	24.67%	–	–
SUE model (collector)	2,027	12.49%	6:30–7:30	3:30–4:30
Loop detector data (2005)	737	4.54%	7:30–8:30	4:30–5:30
Free-flow speed for unmetered ramps	508	3.13%	–	–
Estimated from 2008 GPS survey	362	2.23%	6:00–9:00	2:00–7:00
Metered ramp delay model	122	0.75%	7:30–8:30	4:30–5:30
MnDOT DataExtract tool (2007)	73	0.45%	7:30–8:30	4:30–5:30
MnDOT DataExtract tool (2006)	48	0.29%	7:30–8:30	4:30–5:30
MnDOT DataExtract tool (2005)	33	0.20%	7:30–8:30	4:30–5:30
Free-flow speed (collectors/distributors)	32	0.20%	–	–

The most recent version of this network was updated in 2009, and it provides an adequately accurate representation of the state of the regional road network in 2010. Because accurate accessibility evaluation depends on an accurate representation of network structure, this network dataset must be maintained and updated for future accessibility evaluations as changes are made to the regional road network. Ideally, this maintenance would be a joint effort between local transportation planners, engineers, and researchers in order to avoid duplication of effort and establish a consistent reference model of the regional road network. [8]

It should also be noted that the current version of the planning model network is designed for use with TAZs defined based on 2000 Census geography. It includes features specifically created to model travel to and from TAZ centroids. The Metropolitan Council's release of new TAZ designations based on 2010 Census geography, described in Section 4.2.3, will require modifications to the model network to provide connections to and from the new TAZs. As of this writing, the Metropolitan Council had not yet released an updated model network.

Freeway Speeds

Instrumentation of the regional freeway network with embedded loop detectors increased rapidly between 1995 and 2005. When evaluating accessibility in this period, Access to Destinations researchers supplemented loop detector measurements with estimates and imputations from a variety of other sources. By 2010, the regional freeway network (as well as some major arterials) was very well-instrumented. Aside from short gaps caused by equipment malfunctions or maintenance, link speeds calculated from loop detector data are generally available throughout each day and throughout each year. Because they are direct measurements of traffic and can be expected to be available for the foreseeable future, loop detector data are an excellent resource for evaluating regional accessibility on an ongoing basis. [9]

Annual accessibility evaluation depends on analysis of loop detector data for an entire year. The Minnesota Traffic Observatory (MTO), operated and hosted by the University of Minnesota, maintains an archive of freeway loop detector data going back to 1994 and provides an interface for bulk downloads of all loop detector data by quarter. This same data is available from other sources, but can generally only be accessed for a single day or for a single location at a time. Ensuring the continued availability of bulk loop detector data will help streamline data collection efforts in a process for ongoing accessibility evaluation.

In addition to the loop detector volume and occupancy data, this analysis uses freeway network information compiled as part of MnDOT's Intelligent Roadway Information System (IRIS). Specifically, the IRIS network configuration file ("metro_config.xml") provides a description and the location of each detector as well as the stations and corridors they comprise. Continued access to this information is important to the functionality of the tools developed for this analysis.

Arterial and Collector Speeds

In contrast to freeways, local arterials and collectors are only sparsely instrumented. To produce accurate speed estimates for these network links, earlier Access to Destinations research combined a travel demand model implemented by the Metropolitan Council, a stochastic user equilibrium (SUE) assignment process, and a calibrated speed prediction function which relies on estimated free-flow speed, roadway properties, and signal timing information. This system for modeling speeds on arterials is sophisticated, and is indispensable for evaluating mobility and accessibility in planning scenarios such as those explored in. However, its complexity, calibration requirements, and fundamental nature as a model rather than a measurement are undesirable qualities from the perspective of ongoing accessibility evaluation. [10, 8]

To establish an alternative, this analysis seeks to identify and evaluate a source for speeds on arterials and collectors which fundamentally relies on direct traffic measurement. Speeds measured using GPS are the most promising, and the Metropolitan Council has purchased link-level speed data from a global GPS navigation system vendor. As this report was being prepared the Council was in the final stages of preparing this data for use in regional transportation research and planning.

Because that data is not yet available, this project makes use of speed measurements made by GPS during a University of Minnesota research project conducted during the second half of 2008. [11] This data represents a very accurate measurement of traffic speeds at specific locations and specific times. However, both the sample size and the study period were relatively small, and not sufficient to produce robust speed estimates across the entire metropolitan region. Nevertheless, they represent the most accurate and comprehensive measurement of arterial and collector speeds available, and using this source avoids the necessity of reimplementing a lengthy and complex SUE-based estimation that is undesirable for future use.

This GPS data entails an important difference compared to arterial and collector speeds used in earlier Access to Destinations research. While the SUE-modeled speeds represented predicted speeds during the morning and afternoon peak hours, the 2008 GPS speed data is aggregated to much wider peak periods: 6:00–9:00 AM and 2:00–7:00 PM. Due to this wider scope of averaging, arterial and collector speeds used in this analysis are generally higher than those used in previous evaluations of accessibility by automobile (Table 4.2). [11, 5]

Table 4.2: Average link speeds by road classification (2005 and 2010)

Road Classification	**Roadway length (km)**	**% of total roadway length**	**Average 2005 AM speeds (km/h)**	**Average 2010 AM speeds (km/h)**	**% differ- ence**
Undivided Arterial	6,634	40.87%	41.53	49.44	19.07%
Centroid Connector	4,005	24.67%	37.01	37.01	0.00%
Collector	2,022	12.45%	43.02	42.61	-0.95%
Divided Arterial	1,015	6.25%	34.13	50.86	49.03%
Expressway	757	4.66%	46.50	66.35	42.69%
Metered Freeway	724	4.46%	84.75	90.47	6.76%
Unmetered Freeway	415	2.55%	89.95	101.73	13.10%
Unmetered Local Ramp	323	1.99%	59.69	58.99	-1.16%
Metered Local Ramp	169	1.04%	56.13	60.57	7.91%
Unmetered System Ramp	69	0.42%	60.77	65.81	8.29%
Metered System Ramp	67	0.41%	58.04	64.99	11.97%
C/D Road	34	0.21%	80.48	74.97	-6.85%
Total	16,232	100%	45.01	50.15	11.43%

Transit

Transit users interact with a different type of network than automobile drivers. Instead of navigating physical infrastructure, transit users move through a more abstract network of bus and rail routes provided by the transit operator. Modeling the transit network therefore requires different techniques than modes which rely solely on physical infrastructure.

Earlier phases of the Access to Destinations project relied on schedule data requested from Metro Transit and exported from a proprietary scheduling software system. [12, 13] While this was sufficient for calculating transit travel times, the proprietary format required researchers to develop custom tools for reading the schedule data. In 2009, Metro Transit began publicly releasing detailed schedule information in the General Transit Feed Specification (GTFS). GTFS was developed in 2005 by Google, Inc. and Portland TriMet in order to power Googles transit trip planner, and has been rapidly adopted throughout the world. This new data format not only provides greater schedule detail but also allows the use of tools which are compatible with transit schedule information released by agencies around the world. Additionally, the proliferation of transit trip planing systems which depend on GTFS data make it reasonable to expect that this data source will be available for the foreseeable future.

Unfortunately, Metro Transits GTFS schedule releases are not officially archived—each release replaces the last. As a result, Metro Transit schedules released in 2010 and 2011 are no longer available in GTFS format. To represent 2010 transit schedules, this report uses the Metro Transit schedule which took effect on November 7, 2009. Future analyses of regional transit accessibility would benefit from the creation of an official archive of local transit schedules in GTFS format.

It should also be noted that while Metro Transits initial GTFS releases included schedule information for all transit providers in the region, in June of 2011 routes operated by the Minnesota Valley Transit Authority (MVTA) were removed from the Metro Transit GTFS feed, and since that date have been published in a separate GTFS release by MVTA. Future analyses of regional transit accessibility will need to accommodate this change by merging the two datasets to form a complete representation of regional transit schedules.

4.2.3 Geospatial Resolution

It is important to evaluate accessibility at an appropriate level of geographic detail. Evaluation at a very fine resolution (such as at the Census block level) is possible but, for motorized transportation modes, provides few benefits relative to its costs. The complexity of calculating a travel time matrix scales with the square of the number of geographic units being analyzed, so a tenfold increase in the number of geographic units results in a hundredfold increase in calculation times. Differences in auto and transit travel times for adjacent blocks are often small or negligible, so a block-level analysis would provide only a marginally more detailed representation of accessibility.

Intermediate geographic levels such as Census tracts and TAZs provide a useful balance between meaningful detail and calculability. In particular, the TAZ level is especially well-suited for accessibility analysis because TAZs are created specifically to encompass areas with similar transportation characteristics. Additionally, earlier phases of the Access to Destinations project developed models of the regional road network that incorporate features which specifically enable TAZ-level analysis. For these reasons, this report evaluates accessibility based on the Metropolitan Council's 2000 TAZ dataset. [10, 8, 5]

In March of 2012, the Council released an updated set of TAZ definitions based on 2010 Census geography. This update increases the number of TAZs in the core 7-county metro area from 1,201 to 3,030 and expands TAZ coverage into Chisago, Goodhue, Isanti, Le Sueur, McLeod, Pierce, Polk, Rice, Sherburne, Sibley, St. Croix, and Wright Counties. Within the core 7-county metropolitan area, smaller TAZs will allow a higher-resolution evaluation of accessibility, which will especially increase representational accuracy for transit and non-motorized transportation modes.

This change also brings some challenges: a greater number of analysis zones will increase the computational complexity of travel time calculation. Though established methods will remain useful they will take longer to implement. Also, smaller TAZs will increase the evaluation process' sensitivity to the geographic scale at which land use data sources are available. In the 7-county metro area, the sizes of the new TAZ are roughly the same as Census block groups, and are often smaller. Making use of data sources only available at the block group level or higher will require additional processing for assignment to TAZs. Fortunately, the LEHD-derived data sources currently employed in evaluating accessibility to jobs, workers, and population are all available at the much smaller Census block level.

Unfortunately, the 2010 TAZ designations are not ready for use in this accessibility evaluation. As noted in Section 4.2.2, the Councils model network which will accommodate the 2010 TAZs remains in development at the time of this writing; the calculation of auto travel times depends on this model network. While it would be possible to calculate transit accessibility using 2010 TAZ definitions, the gain in geographic resolution would be offset or outweighed by the loss of direct comparability with auto accessibility, as discussed in Section 3.1. For these reasons, this evaluation continues the use of 2000 TAZ definitions for both auto and transit accessibility calculations.

4.3 Methodology

This section provides an overview of the methodology used in evaluating accessibility by auto and transit in the Twin Cities metropolitan area in 2010, as well as a discussion of the development of that methodology. For details regarding ongoing implementation of this methodology and instruction for using various software tools, see Section 5 and the Appendix.

4.3.1 Land Use

All of the land use data sources described in Section 4.2 are available at the Census block level. However, as discussed in Section 4.2.3, this level of detail is unnecessarily fine-grained for analysis using the regional planning network, which is designed for use at the TAZ level. To facilitate a TAZ-level accessibility evaluation, block-level land use data were aggregated to TAZs by centroid inclusion: for each land use category, a TAZ was assigned a value equal to the sum of the values of the Census blocks whose centroids lie within it.

4.3.2 Travel Time

Earlier components of the Access to Destinations research project have focused primarily on evaluating travel times during three distinct periods of the day: an AM peak period, a PM peak period, and an off-peak period representing midday travel times. However, different research components have used varying definitions for these periods. For example, an evaluation of accessibility by auto [5] used the period from 7:30–8:30 AM to represent the AM peak period, while an evaluation of accessibility by transit [13] used the period from 7:00–9:00 AM.

These decisions can have dramatic effects on the results of accessibility evaluations. Parthasarathi et al. [14] used data collected during the 2000 Twin Cities Travel Behavior Inventory to estimate overall average speeds on the road network throughout the day. The results, illustrated in Figure 4.1, demonstrate the importance of carefully selecting time periods for accessibility analysis. Because average speeds fall and rise rapidly during the onset and offset of the peak periods, selecting a narrow period for analysis will result in lower average speeds, and therefore lower accessibility, than will selecting a wider period for analysis (assuming that the analysis period is centered on the absolute peak).

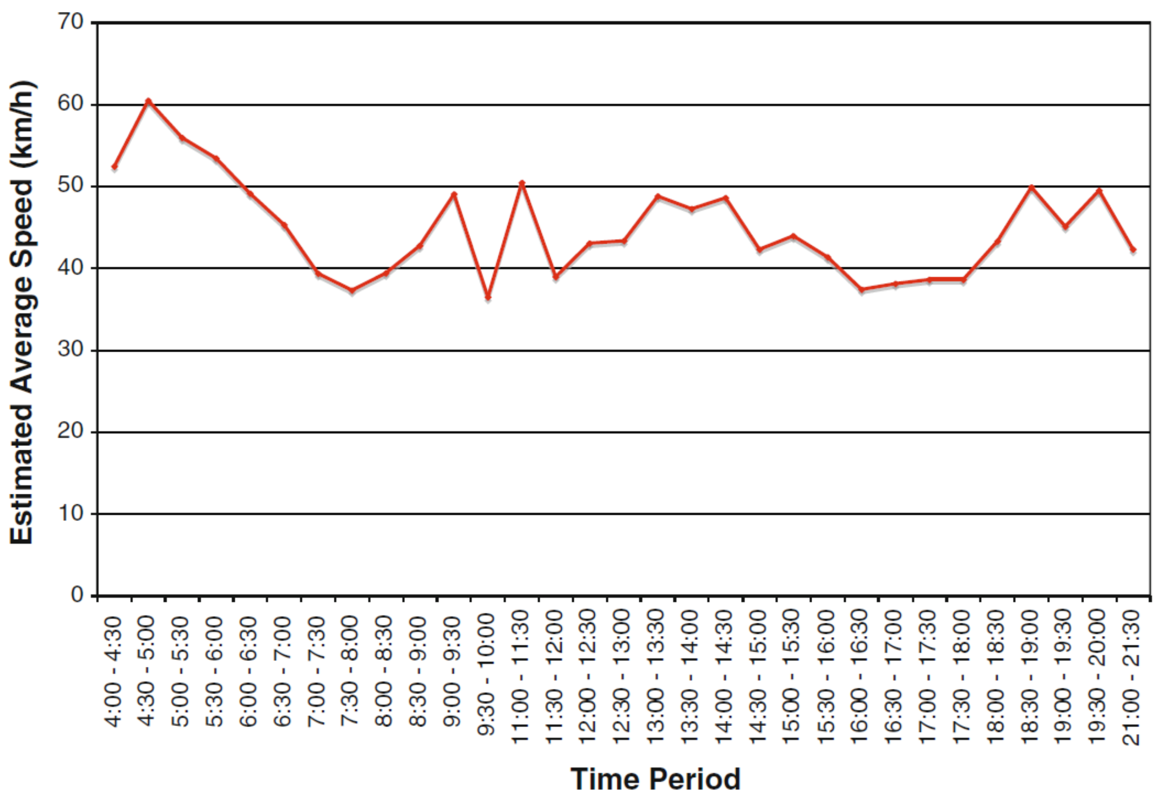

Figure 4.1: Estimated average speeds throughout the day (Parthasarathi et al., 2011)

Additionally, comparisons of the accessibility provided by different modes is only meaningful if the same time periods are used for each. It is also important to note that the duration of the selected time period can have effects specific to scheduled transportation systems such as transit. Because departures using transit are possible only at scheduled trip times, an accessibility evaluation for a specific time period will only represent the accessibility provided by trips which depart during that time period.

Selected Time Periods

This analysis, wherever possible, adopts the standard of using 7:00–9:00 AM to represent the AM peak and 4:00–6:00 PM to represent the PM peak; exceptions are explicitly noted. These time periods were established after discussion with the advisory panel in anticipation of using a GPS-based speed dataset purchased by the Metropolitan Council which uses the same definitions. Ultimately, this dataset was not available before the current analysis was completed.

Freeway Speeds

Freeway speeds are derived from direct traffic observations made by embedded loop detectors. These detectors record, at 30-second intervals, the observed traffic volume and occupancy. When combined with an estimation or assumption of the detector's effective field length, these fundamental measurements can be used to make a very accurate estimate of vehicle speeds.

In earlier Access to Destinations research, Kwon & Klar [9] implemented a method for performing this estimation. They also implemented a sophisticated multi-stage imputation process for estimating speeds during gaps in loop detector data coverage. These methods were implemented using Microsoft Visual Basic to create tools which facilitated the calculation of freeway travel times for arbitrary time periods. Output from these tools was used in subsequent Access to Destinations projects.

Unfortunately, those tools are no longer useable for two reasons. First, portions of the original code are incompatible with recent revisions to Microsoft's Visual Basic programming environment. Automated update tools were able to translate the bulk of the software's functionality, but inconsistencies remain in the user interface. Second, and more critically, the original tools made use of a proprietary code library which is no longer functional.

In order to calculate freeway travel times for this project and to provide a tool that can be used reliably in the future, the original speed calculation and imputation methods were completely reimplemented. The new implementations are based on the original source code and are intended to be algorithmically identical. Two new programs were created: TrafficReader, a library which reads the volumes and occupancies stored in loop detector data files and can either report them directly or convert them to speeds; and MNFSpeedCalc, a program which gathers speeds using TrafficReader and then performs imputation and reports averages and summaries over time. Both are implemented in Python, and are open-source, cross-platform tools that can be used either individually or as components of more complicated software packages.

Appendix E provides detailed instructions for using the Cumulative Opportunities Accessibility tool. The source code is available online at
https://github.com/NexusResearchGroup/MN-Freeway-Speed-Calc

To validate this reimplementation, the new tools were used to calculate freeway link speeds using 2005 loop detector data, and the results were compared with the link speeds for 2005 calculated using the original tools for earlier Access to Destinations projects. The difference in average link speeds calculated by the two implementations is 0.85%.

Estimating Effective Detector Field Lengths

Calculation of vehicle speeds based on the volume and occupancy measurements provided by loop detectors relies on an accurate estimation of each detector's effective field length, which in turn depends on the average length of the vehicles which pass over that detector. In Kwon and Klar's original implementation, as well as in this projects reimplementation, effective field lengths are estimated endogenously from the data for each detector. [9]

For each detector, the estimation process identifies samples where occupancy is less than 10%. It is assumed that when occupancies are in this range, vehicles are travelling at the local speed limit. This assumption allows the calculation of average effective field length from volume and occupancy. [9]

It is important to note some likely biases in this method. First, it assumes that vehicles travel at the speed limit when they are unconstrained by traffic density. This is not the case; average driver behavior in low-density traffic conditions can vary dramatically by location and by time of day. Second, it assumes that the percentage of heavy vehicles on the road is the same in all density conditions. This is questionable since heavy vehicles may seek out low-density conditions and avoid peak traffic periods. Finally, it estimates field length based only on observations made when traffic density is low. Such observations will disproportionately occur during off-peak periods and especially at night, increasing the estimation's exposure to time-based patterns in speed and vehicle length variation. Despite these potential biases, this method provides reasonable estimates of link speeds throughout the day, and was validated by comparison with observed travel times collected on a single freeway corridor in 2004. [9]

The IRIS configuration file provides a potential alternative for field length estimations: it supplies a field length attribute for each detector it identifies. Communication with MnDOT staff developing IRIS revealed that these field length values are derived using estimation processes comparable to those employed in earlier Access to Destinations research, and that they are in active use by MnDOT for travel time estimation purposes such as advisory times posted to variable-message signs throughout the metropolitan freeway system.

Using these IRIS-derived field lengths for travel time estimation in accessibility evaluation has some benefits: it makes the speed estimates more consistent with established MnDOT practices, and it somewhat reduces the calculation time required to estimate speeds. For these reasons, the MNFSpeedCalc tool by default uses detector lengths loaded from the IRIS configuration file. However, the code providing endogenous field length estimation remains available and can be specified optionally.

Metered Ramp Delay

In "Measuring Accessibility by Automobile" [5] the authors established a method for estimating the delay incurred by drivers using metered freeway ramps, based on a queueing model and data from ramp loop detectors. This analysis uses the same method:

$$\bar{W} = \frac{\rho}{2\mu\,(1-\rho)} \tag{4.1}$$

The dependent variable $\bar{W}$ represents the average waiting time per vehicle, μ is the rate of arrival and ρ is the ratio of the arrival rate to the service rate. The best available estimates of arrivals to use for this model were the volume counts at the loop detectors at the departure of each ramp. Average peak-hour volumes were compiled for each Wednesday in 2010. The peak hours used were 7:30–8:30 AM and 4:30–5:30 PM (a departure from the standard time periods). The service rates were taken from MnDOT target values used when queue detection is unavailable. Not all ramps were included in the target rate file; for these ramps, the maximum provided rate of 1,714 vehicles per hour was used. [5]

Equation 4.1 is not valid when the arrival rate is greater than the service rate. In general this is not the case; if it were, queues would grow to an infinite length. However, use of this model relies on the assumption that there is no standing queue at the beginning of the peak hour, and that by the end of the peak hour demand has slowed such that service can catch up. The peak hour is not necessarily the same at every ramp, and may be earlier, later, longer, or shorter depending on location. This caused ρ to exceed 1 in some cases, which by Equation 4.1 would result in negative delay. In these cases, the service rate was increased to at least the arrival rate plus 10 percent. The resulting average delay for each metered ramp link were added to the link travel times after all other speed calculations and estimated were completed. [5]

As noted in earlier research, the impact of metered ramp delays on average peak hour travel times is very small. For example, in 2010 the average metered ramp delay between 7:30 and 8:30 AM was just 5.5 seconds, 85% of all ramps had average delays of less than 10 seconds, and the maximum average delay was 49.3 seconds (Figure 4.2). These very low average delays mean that metered ramps have only a marginal impact on overall accessibility, and that therefore this calculation adds relatively little value compared to its expense. Additionally, GPS-based speeds sources could further reduce or eliminate the need for estimated ramp delay, since GPS measurements of vehicles using metered ramps would already account for any delay encountered. Therefore, ramp delay estimation is not considered necessary for future evaluations of accessibility.

Arterial and Collector Speeds

As described in Section 4.2.2, this analysis discontinues the use of arterial and collector speeds calculated using travel demand modeling and SUE assignment due to their complexity, cost, and lack of basis in direct measurements. In its place, speeds measured using GPS systems are used. The Metropolitan Council has purchased a dataset of estimated speeds produced by a commercial GPS vendor; until it is available for research purposes, this analysis makes use of speed measurements made by GPS during a University of Minnesota research project conducted during the second half of 2008. [11]

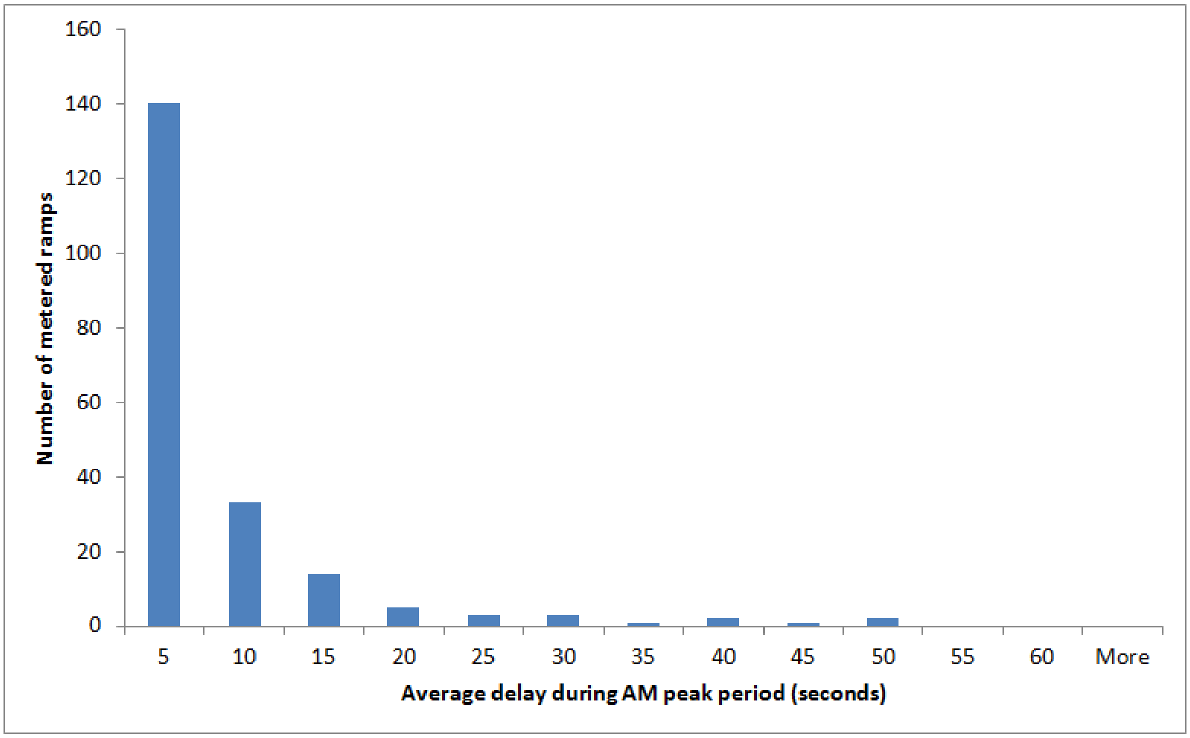

Figure 4.2: Distribution of average delays on metered ramps

Transit

Travel times by transit are calculated using the Nexus Transit Travel Time Calculator, a Java-based tool implementing a variant of the RAPTOR algorithm [15]. As described in Section 4.2.2, this tool draws transit schedule information from data published by Metro Transit and other transit providers in the GTFS format.

Using the GTFS schedule information, travel times are calculated first at the Census block level. The original RAPTOR algorithm finds the single shortest path between two stops in a transit network; the version implemented here is extended to calculate a full shortest-path matrix using each stop in the network as a potential origin. It relies on the assumptions that users are willing to leave at any time within a given time windows; that users will make at most one transfer; and that users will wait at most 15 minutes to make a transfer. This analysis uses 7:00–9:00 AM to represent the AM peak period and 4:00–6:00 PM to represent the PM peak period.

Once the shortest-path matrix is calculated, the results are attached to Census blocks and then aggregated to TAZs. First, each block centroid is associated with the two closest stops, and then any remaining unjoined stops are associated with the closest block centroid. This process guarantees that every block in the study area will be considered. The walking times between stops and block centroids are calculated by multiplying the straight-line distance by an adjustment factor of 1.2 to account for typical levels of circuity on urban streets, and by assuming a walking speed of 5 km/h. [16, 17]

Each block is also associated with a TAZ based on centroid location. The software finds the minimum travel time between each directional pair of blocks using any of their attached stops; if two stops are not connected by the given transit network and trip parameters, the walking time between them is used instead. For each directional pair of TAZs, the travel times for the block pairs within them are averaged to arrive at a final TAZ-level travel time. The travel time from a TAZ to itself is assumed to be zero.

The use of walking times when origins and destinations are not connected by transit results in low levels of accessibility for outlying areas even when they are not connected by transit. Effectively, the result is a composite measure of accessibility using the minimum travel time provided by walking or transit. This also indirectly highlights the fact that currently this method for calculating transit travel times does not take park-and-ride facilities into account—it assumes that all access to transit stops is made by walking.

Appendix E provides detailed instructions for using the Nexus Transit Travel Time Calculator. The source code is available online at
https://github.com/NexusResearchGroup/Nexus-Transit-Travel-Time-Calculator.git

4.3.3 Calculating Accessibility

Once the appropriate land use and travel time datasets are assembled, calculating accessibility is comparatively straightforward. Based on the results of and the responses to earlier Access to Destinations research phases, this report uses a *cumulative opportunities* measure of accessibility. This approach begins by specifying a mode and travel time of interest, and then counts the number of opportunities that can be reached via that mode within that travel time. For example, this measure can be used to identify the number of employment opportunities that can be reached within 30 minutes by car from a specific residential location. [3]

$$A_{i,co} = \sum_{j=1}^{n} O_j f\left(C_{ij}\right) \tag{4.2}$$

$A_{i,co}$ = cumulative opportunities accessibility from a zone (i) to the considered type of opportunities

O_j = number of opportunities of the considered type in zone j (e.g., employment, shopping, etc.)

C_{ij} = generalized (or real) time or cost of travel from i to j

$f\left(C_{ij}\right)$ = impedance function

Using the cumulative opportunities measure, $f\left(C_{ij}\right)$ is defined as 1 if $C_{ij} < T$ and 0 otherwise. T is the travel time threshold for which we will compute the number of activities that can be reached.

An important advantage of the cumulative opportunities measure is its simplicity of interpretation and communication. Because the final metric is an actual count of reachable destinations, it can be easily understood by a wide range of audiences. Additionally, changes in land use or the transportation system have intuitive effects on cumulative opportunities measures of accessibility. For example, if two new banks open within 10 minutes of a location, that locations cumulative opportunities accessibility to banks will increase by 2.

Earlier Access to Destinations research also explored other methods of calculating accessibility, most notably a variety of *weighted opportunities* methods. These methods theoretically provide a more accurate representation of accessibility by weighting the value of each destination by some function of the cost of accessing it. However, these gains in accuracy depend on sensitive model calibration, the techniques for which are the subject of ongoing academic research. This, combined with decreased ease of interpretation and communication, make weighted opportunities methods less desirable for use in an ongoing performance evaluation tool.

Implementation

A software tool was created that facilitates simple and replicable calculation of cumulative opportunities accessibility. This program, the Cumulative Opportunities Accessibility tool, is implemented in Python as a tool for the ArcGIS 10 environment. Figure 4.3 illustrates the tool interface. It is designed for flexible, general-purpose accessibility calculation and can provide results for any transportation mode, any land use type, and any region for which data is available. All maps, tables, and figures included in this report which describe accessibility in 2010 are derived from results generated using the Cumulative Opportunities Accessibility tool.

This flexibility is made possible by the specification and documentation of standard formats for input and output datasets. While this places a small burden on the user who must prepare the datasets for accessibility calculations, in most cases these requirements are limited to specifying appropriate file names and table column names.

The ArcGIS environment and the Python programming language were chosen for two important reasons. First, a tool implemented within ArcGIS provides fast, easy integration with ArcGIS workflows used to generate inputs for accessibility calculation and to analyze and create maps based on the outputs. Second, use of the popular, open-source, and cross-platform Python programming language makes the core accessibility calculation algorithms very portable. While the current implementation relies on ArcGIS for input and output operations, the actual accessibility calculation is not specific to ArcGIS and can be adapted to other environments with relatively little effort.

Appendix G provides detailed instructions for using the Cumulative Opportunities Accessibility tool. The source code is available online at
`https://github.com/NexusResearchGroup/Cumulative-Opportunities-Accessibility-Tool`

4.3.4 Summarizing Accessibility

Calculation of accessibility, as described above, takes place at the TAZ level. However, in planning and policy contexts it is often necessary to make comparisons at higher levels of geography. For example, policymakers may be interested in the relative accessibility experienced by residents of Hennepin and Ramsey Counties. To facilitate such a comparison,

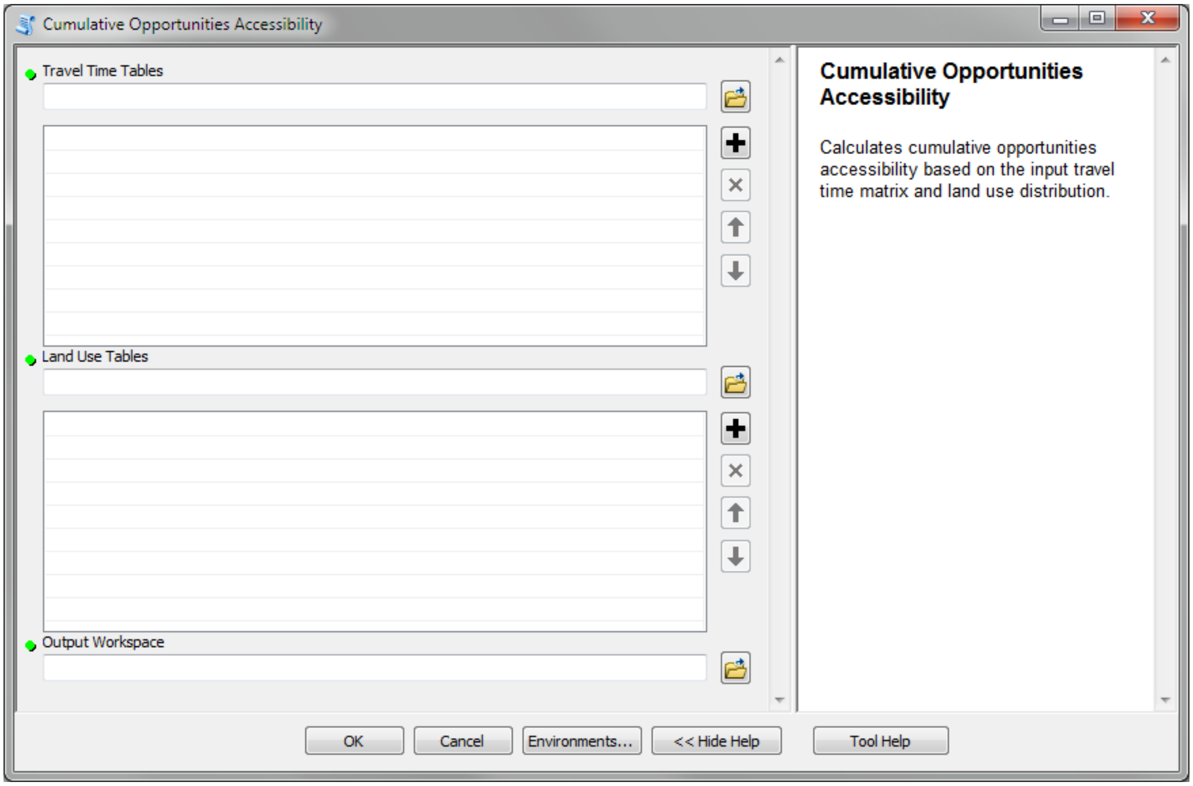

Figure 4.3: The Cumulative Opportunities Accessibility tool in ArcGIS 10

this analysis provides *weighted accessibility sumaries* for each county in the metropolitan area. These summaries are weighted averages of the accessibilities for the TAZ that make up each county, weighted by the population in each TAZ which experiences that accessibility.[3] Equation 4.3 describes the method used to calculate this summary:

$$A_{pw} = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} P_i} \tag{4.3}$$

A_{pw} = person-weighted average accessibility of all subzones
P_i = population in subzone i

4.4 Results

4.4.1 Land Use

Table 4.3 describes the total population, the total number of jobs, and the total number of workers identified in the 7-county metropolitan region using the LEHD and Census data sources described in Section 4.2. For comparison, the same data points used in accessibility evaluations for 1995, 2000, and 2005 are included. [5]

Table 4.3: Land use totals and growth rates (1995–2010)

Year	Population		Employment		Labor	
1995	2,465,389	–	1,449,268	–	1,199,732	–
2000	2,642,056	(+7.17%)	1,603,295	(+10.63%)	1,442,079	(+20.20%)
2005	2,663,303	(+0.80%)	1,554,369	(-3.05%)	1,408,238	(-2.35%)
2010	2,849,561	(+6.99%)	1,556,026	(+0.11%)	1,400,583	(-0.54%)

Effectively, these represent the total number of opportunities of each type that are available in the region, and are the upper bounds of possible values from a cumulative opportunities measure of accessibility.

4.4.2 Travel Time

Table 4.2 describes the average speeds on roadways links during the AM peak period in 2010 by road classification. For comparison, the average AM peak hour speeds for the same link classifications that were used in an accessibility evaluation for 2005 are included. It is important to recognize that the majority of the differences in speeds between 2005 and 2010 are due to data source changes rather than changes in the real-world transportation network. In the 2005 study, speeds for these roadway classifications were drawn almost entirely from SUE-based modeling which predicted AM (6:30 – 7:30) and PM (3:30 – 4:30) peak hour speeds. In this 2010 study, speeds are drawn from GPS measurements which were averaged to AM (6:00 – 9:00) and PM (2:00 – 7:00) peak periods. The road classifications with the largest speed increases over 2005 are divided arterials (49% increase), expressways (43% increase), and undivided arterials (19% increase).

The speed differences for these road classifications demonstrate the importance of selecting an appropriate period of analysis and applying it consistently. Because they make up a combined 51.8% of the total length of the network, the higher speeds used for these links has a dramatic effect on accessibility results, effectively rendering the 2010 results incomparable to the 2005 results.

Freeway and ramp speeds are also higher for 2010 than for 2005. Speeds for some (24%) of these links are drawn from the same peak period GPS measurements, which therefore account for some of the increase over the 2005 peak hour speeds. But over three quarters of freeway and ramp speeds are calculated from loop detector observations, and in these cases speed increases should represent reality. For links whose speeds were calculated from loop detector data in both 2005 and 2010, and therefore are averaged over the same AM peak period of 7:30 – 8:30, average speeds increased 6.1%, from 87.5 km/h (54.3 mph) to 92.8 km/h (57.7 mph).

Since speeds on urban freeway systems are generally not expected to increase over time, it is worth investigating this result. Table 4.4 summarizes the total highway lane miles and total annual highway vehicle kilometers travelled (VKT) in the 7-county metro area for 2005 and 2010. During that period, total highway lane miles increased by 3.20%, while total annual highway VKT decreased by 2.04%. Effectively, this indicates that less total highway

Table 4.4: Highway lane kilometers and VKT (2005 and 2010, MnDOT Transportation Information System)

	2005	**2010**	**Change**
Highway lane kilometers	5,968	6,159	+3.20%
Highway vehicle kilometers travelled (VKT)	24,785,182,372	24,280,019,863	-2.04%

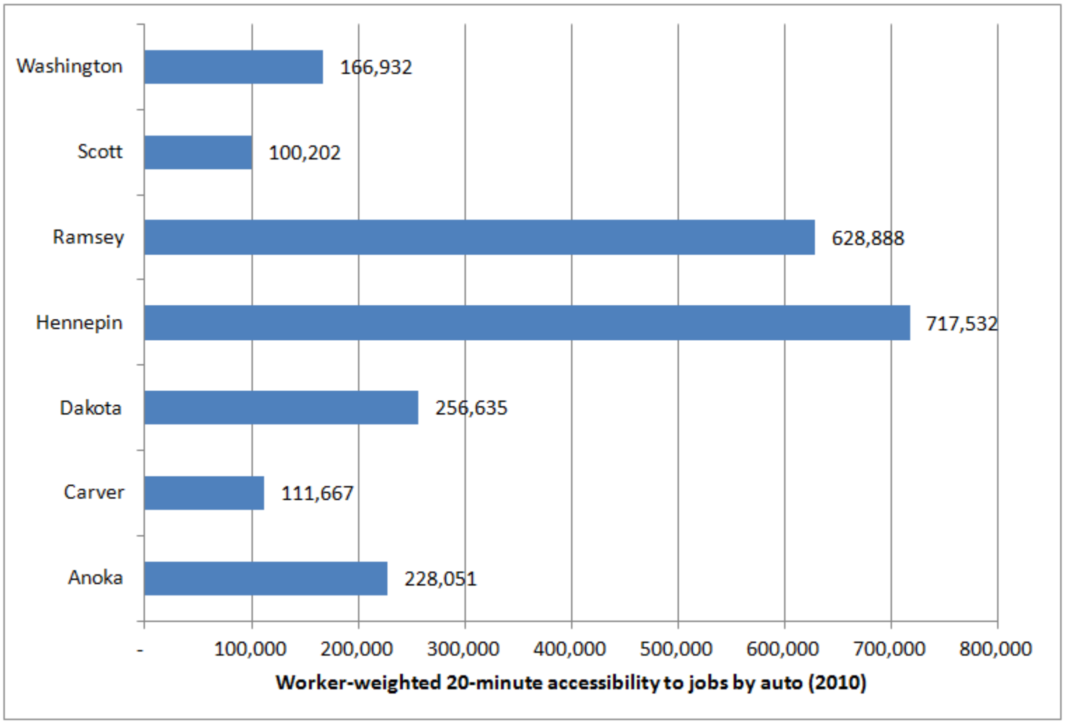

Figure 4.4: Worker-weighted 20-minute accessibility to jobs by county (2010)

travel was distributed over more total highway lane miles, which would correspond to an aggregate decrease in average traffic density. Given this trend, an increase in average link speeds is a reasonable finding. [18]

4.4.3 Accessibility to Jobs

Figure 4.4 describes the worker-weighted 20-minute accessibility to jobs by auto for each county in the metropolitan area. The results highlight the importance of centrality to accessibility: Hennepin and Ramsey Counties benefit from their central locations which allow resident workers to access jobs throughout the area. In contrast, residents of outlying counties such as Scott and Carver Counties experience much lower accessibility. Additionally, these counties are separated from the rest of the metro area by rivers, which limit auto mobility and thereby limit accessibility.

Figure 4.5 through Figure 4.10 illustrate regional accessibility to jobs, by both auto and transit, at 10 minute intervals. These maps reinforce the same general patterns found in evaluations of accessibility for earlier years. However, data source changes make direct comparisons with past results impossible. Most notably and as discussed above, speeds used on arterial and collector roads for 2010 were much higher than the speeds used in evaluations for 1995, 2000, and 2005. As a result, accessibility by auto is higher across the board, and increases more rapidly as the cumulative opportunities threshold is increased.

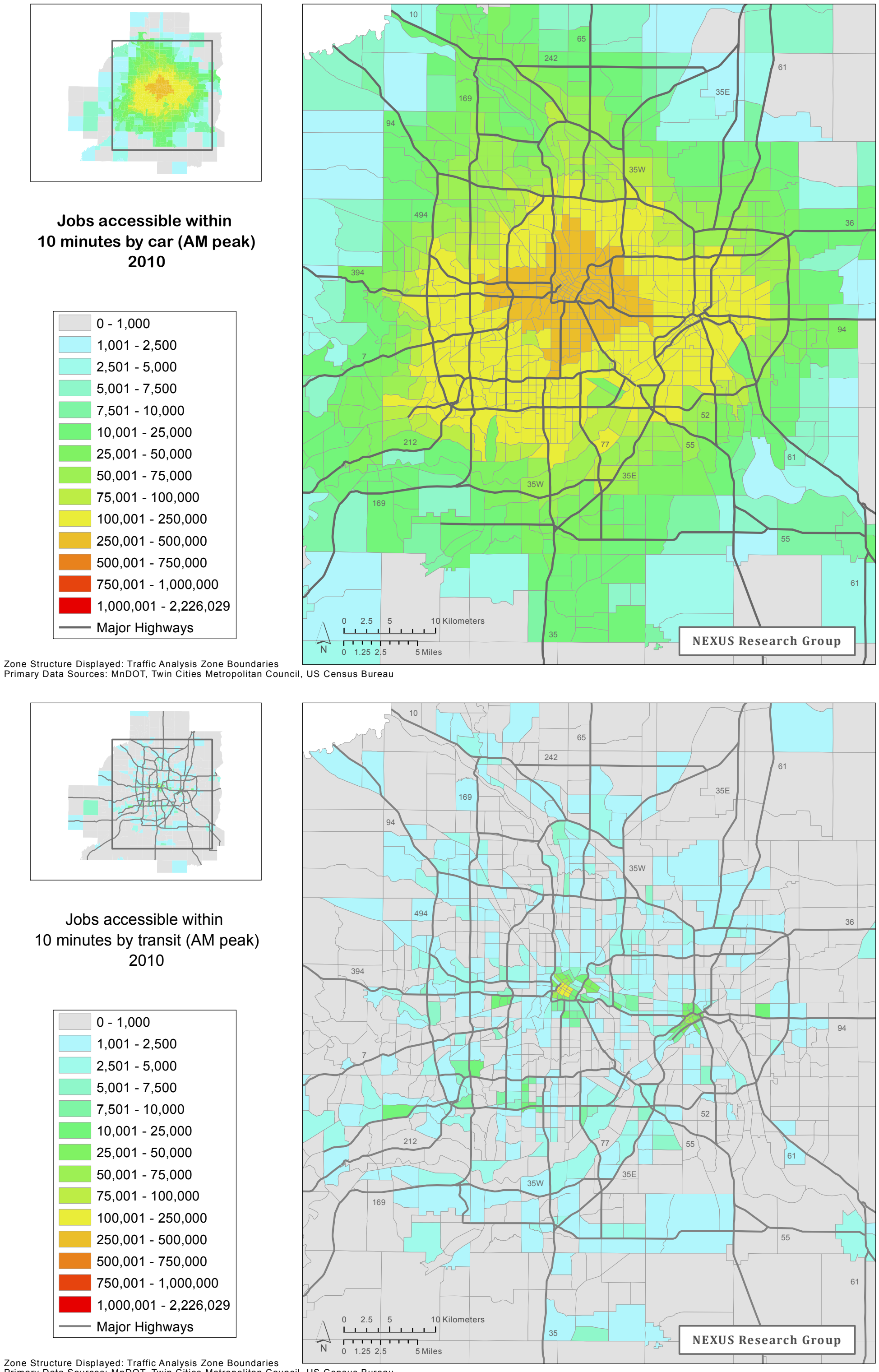

Figure 4.5: 10-minute accessibility to jobs by auto and transit, 2010 AM peak period

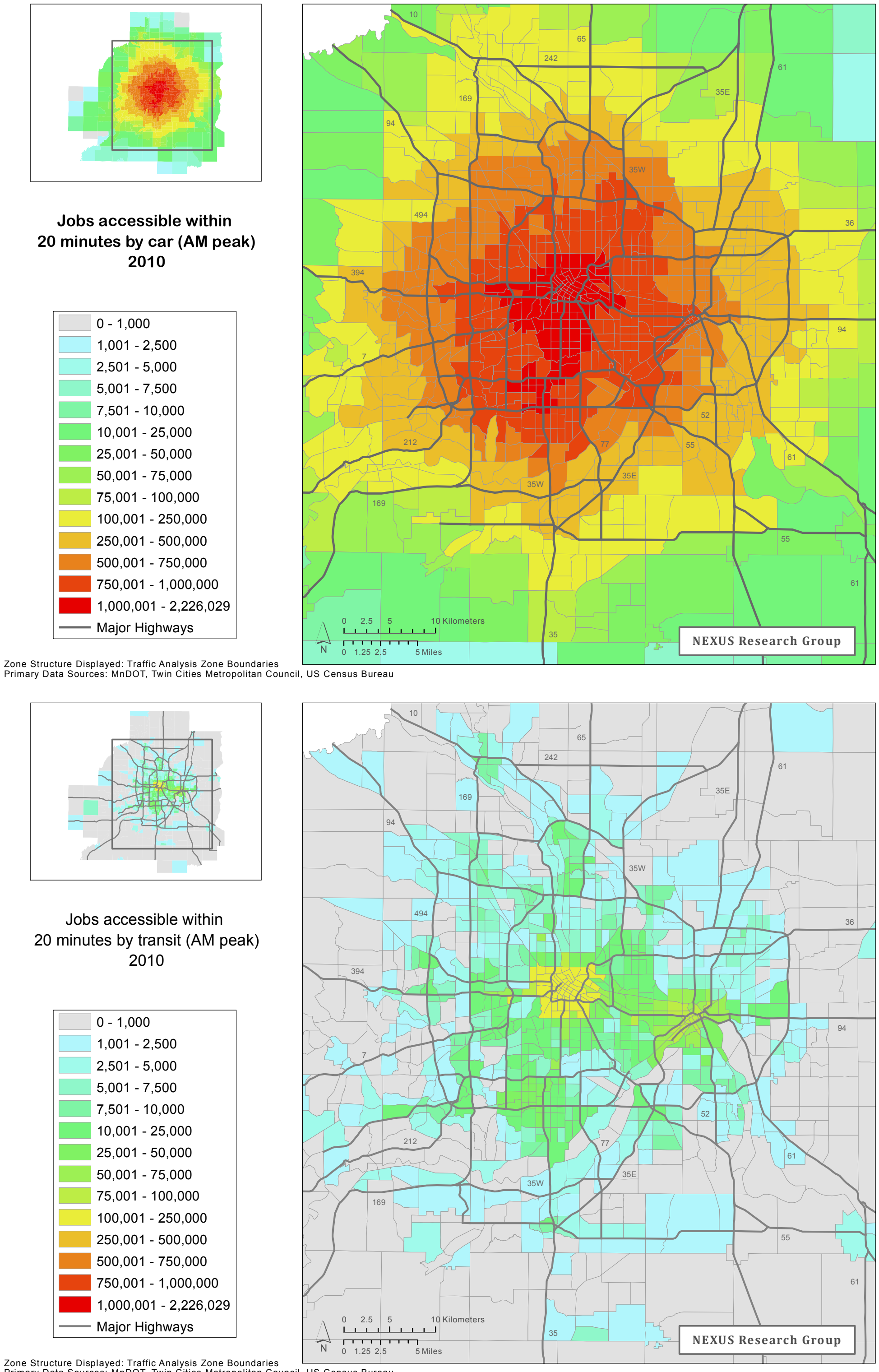

Figure 4.6: 20-minute accessibility to jobs by auto and transit, 2010 AM peak period

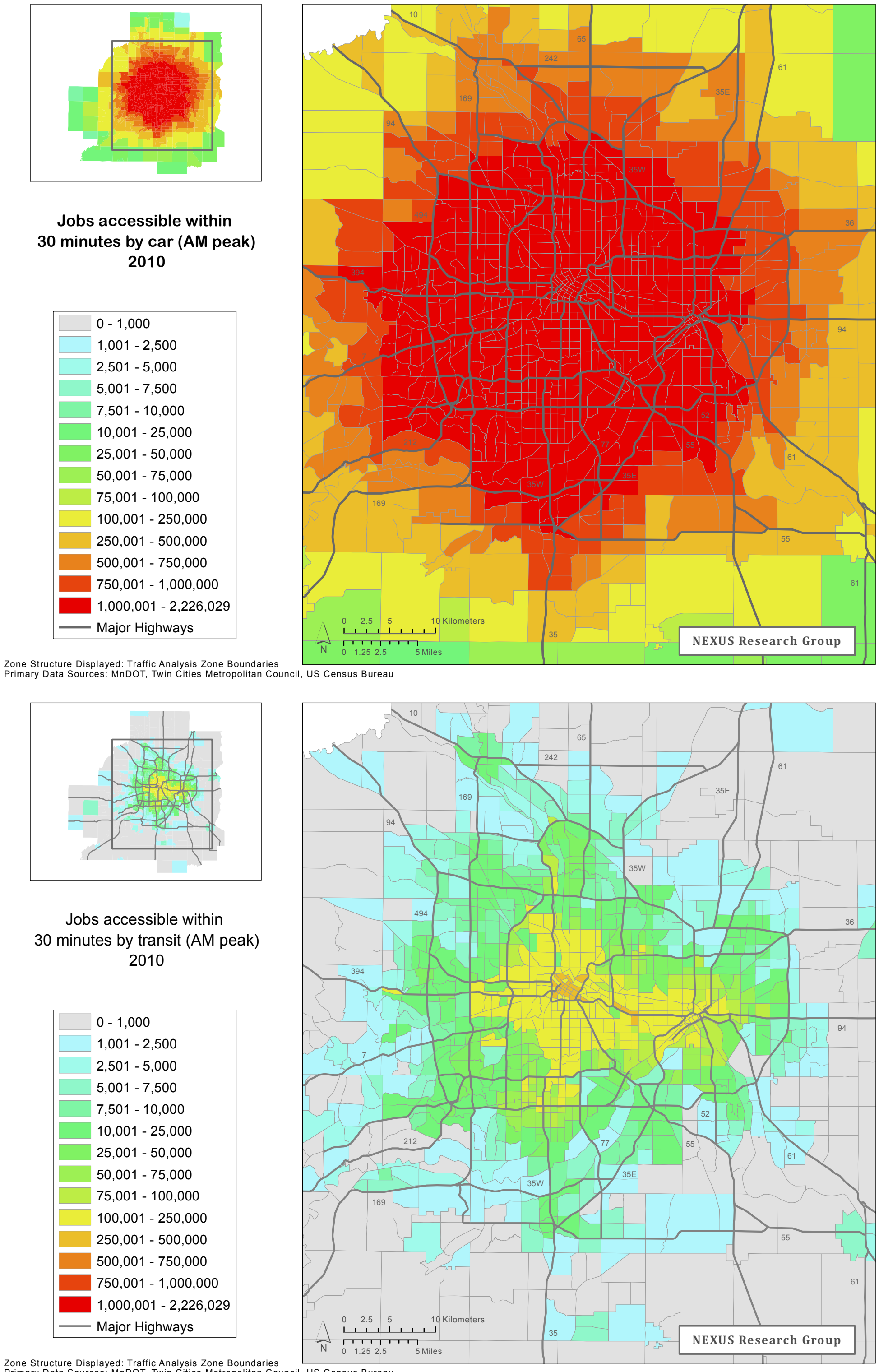

Figure 4.7: 30-minute accessibility to jobs by auto and transit, 2010 AM peak period

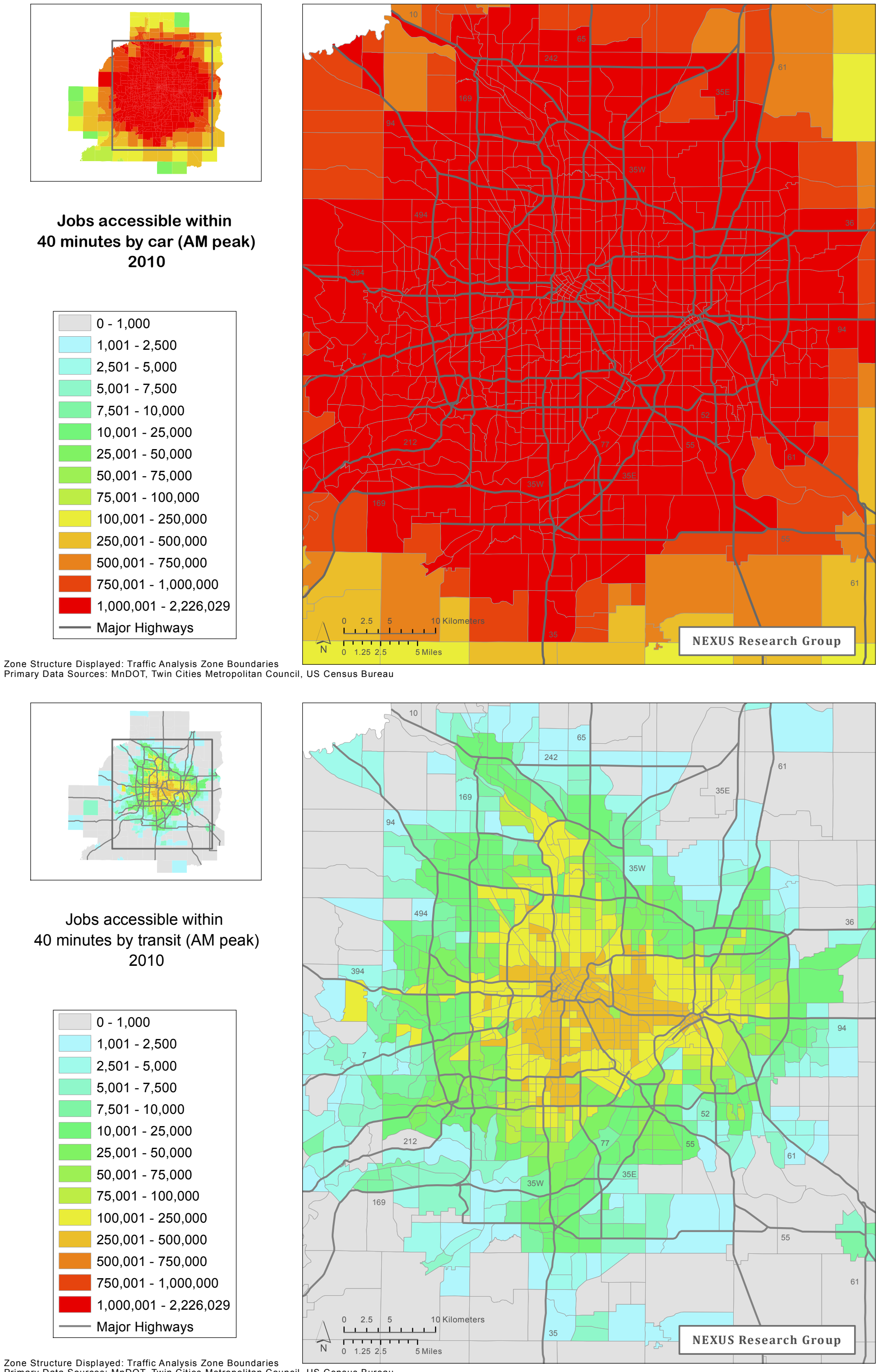

Figure 4.8: 40-minute accessibility to jobs by auto and transit, 2010 AM peak period

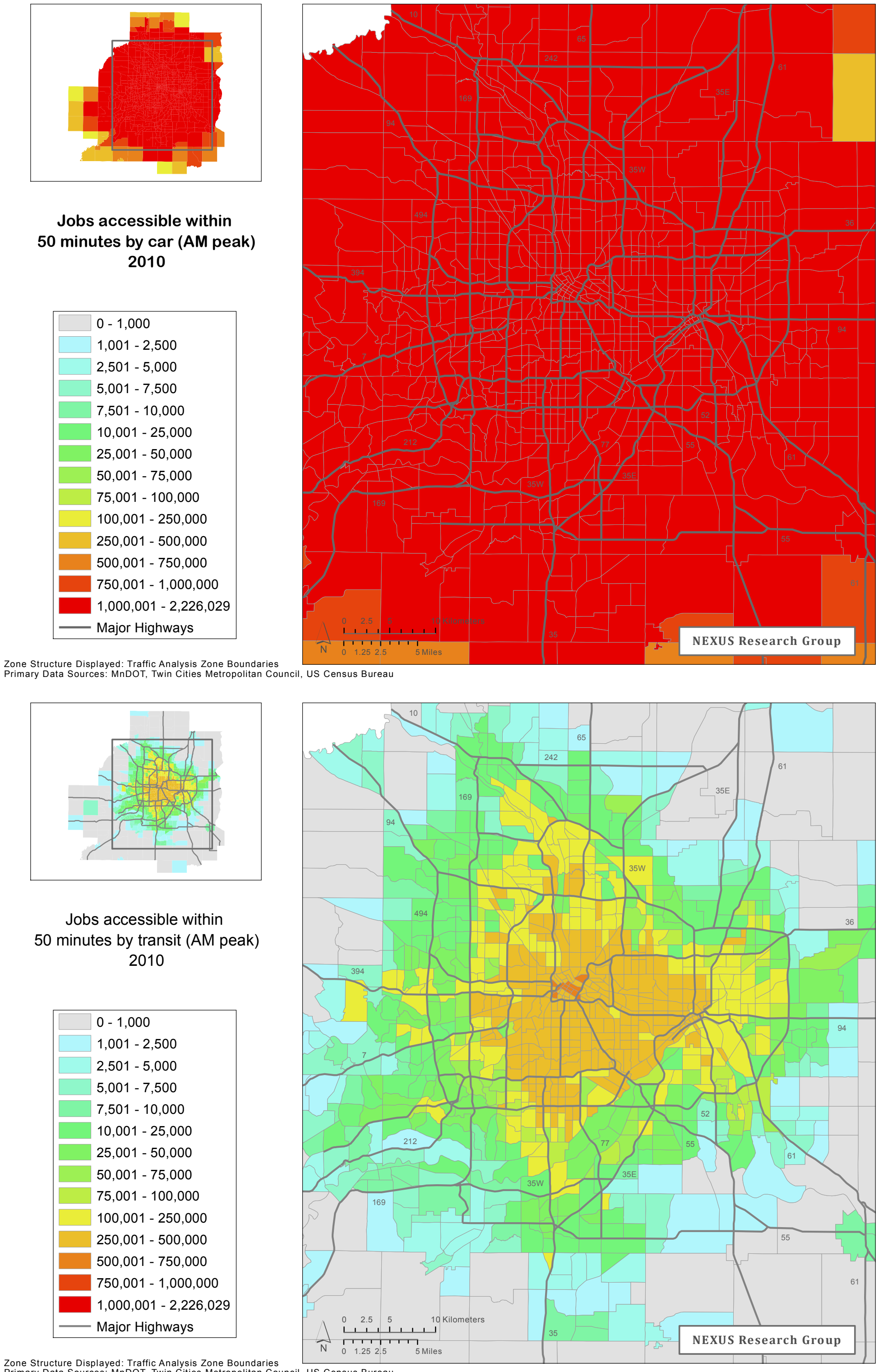

Figure 4.9: 50-minute accessibility to jobs by auto and transit, 2010 AM peak period

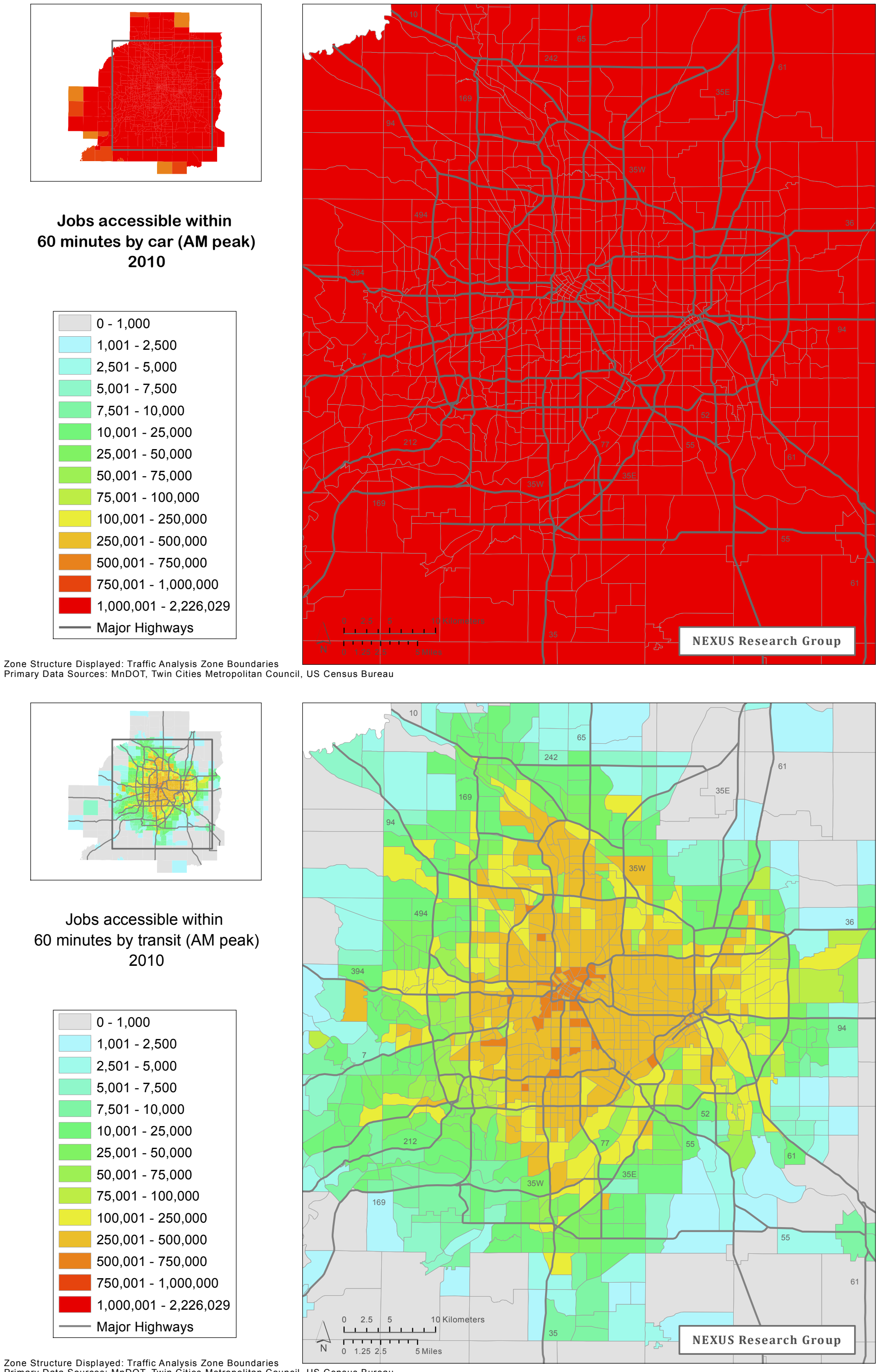

Figure 4.10: 60-minute accessibility to jobs by auto and transit, 2010 AM peak period

4.4.4 Relative Modal Accessibility to Jobs

With cumulative opportunities accessibility calculated for both auto and transit for the same time periods and the same land use data, it is possible to directly compare the accessibility provided by these two separate transportation systems. As discussed in Section 3.1, ratios are a simple but powerful way to perform such comparisons. By taking the ratio of jobs accessible by transit at a given travel time threshold to jobs accessible by auto at the same threshold, a single metric is produces which indicates for each origin TAZ how transit compares with driving for job access. Figure 4.11 though Figure 4.16 illustrate this ratio at 10-minute increments. Several important trends are evident.

First, the 10-minute transit/auto accessibility (T/A) ratio (Figure 4.11) illustrates the effects of a mismatch between geographic unit size and travel time thresholds. In many large, outlying TAZs, the T/A ratio is high—in fact, it is 1.0: the data indicate that transit (or walking) provides access to the same number of jobs within 10 minutes as does driving. This is an artifact of the adopted methodology which allows zero-cost access from any zone to itself. This greatly simplifies calculation but is unrealistic for large zones—effectively, it assumes that all trips start from exactly the centroid of each zone, and that all opportunities are located there as well. In reality, trip origins and opportunities are distributed throughout each zone, and transit/walking might connect only a few of them within 10 mintes, resulting in much lower accessibility. This effect decreases rapidly as the travel time threshold increases; at 20 minutes it is apparently only in the largest outlying TAZs (Figure 4.12), and it is effectively eliminated at 30 minutes (Figure 4.13).

The transit/auto accessibility (T/A) ratio never exceeds 0.4 in any TAZ at any time interval other than 10 minutes (which suffers from the representational inaccuracy described above). This indicates that during the AM peak period, transit never provides access to more than 40% of the number of jobs to which driving provides access. For the vast majority of origins and time thresholds the ratio is much lower; for example, at 30 minutes most TAZ have a T/A ratio of less than 0.05, and only six TAZs have a T/A ratio of 0.2 or higher. The T/A ratio increases for all TAZs as the travel time threshold increases.

It is possible to identify the effects of express transit services which target commuters. At travel time thresholds as low as 20 minutes, corridors and pockets of relatively high T/A ratios are apparent along I-394, along I-35W south of downtown Minneapolis, along I-94 between Minneapolis and Saint Paul, and in the southwest metro area. These highway corridors are served by limited-stop commuter routes, and (outside of the central cities) often offer park-and-ride service. At 50- and 60-minute travel time thresholds, express commuter services departing from locations along I-35W and Highway 77 south of the Minnesota river become apparent.

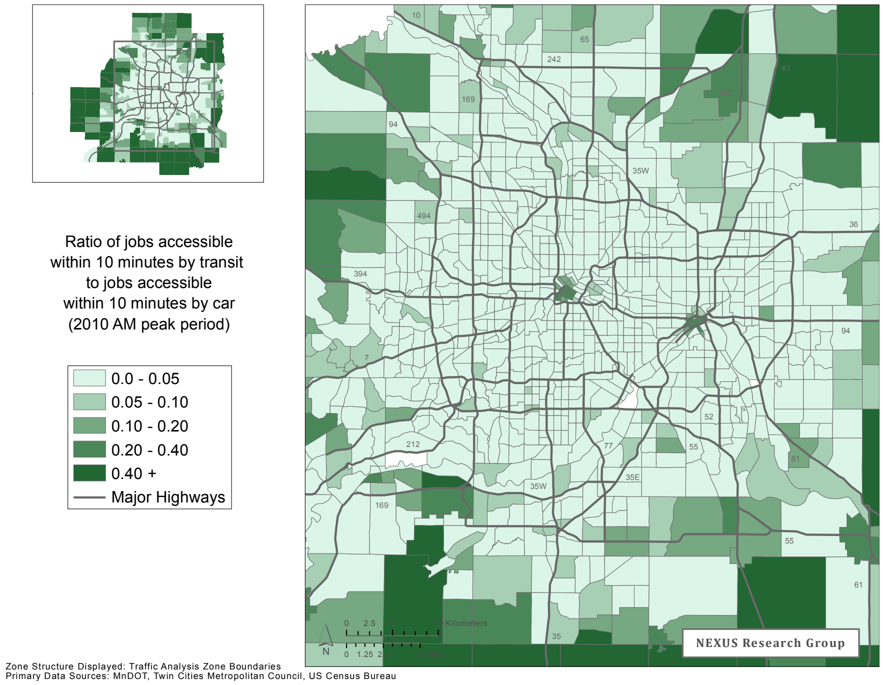

Figure 4.11: Ratio of 10-minute accessibility to jobs by transit to 10-minute accessibility to jobs by auto (2010 AM peak period)

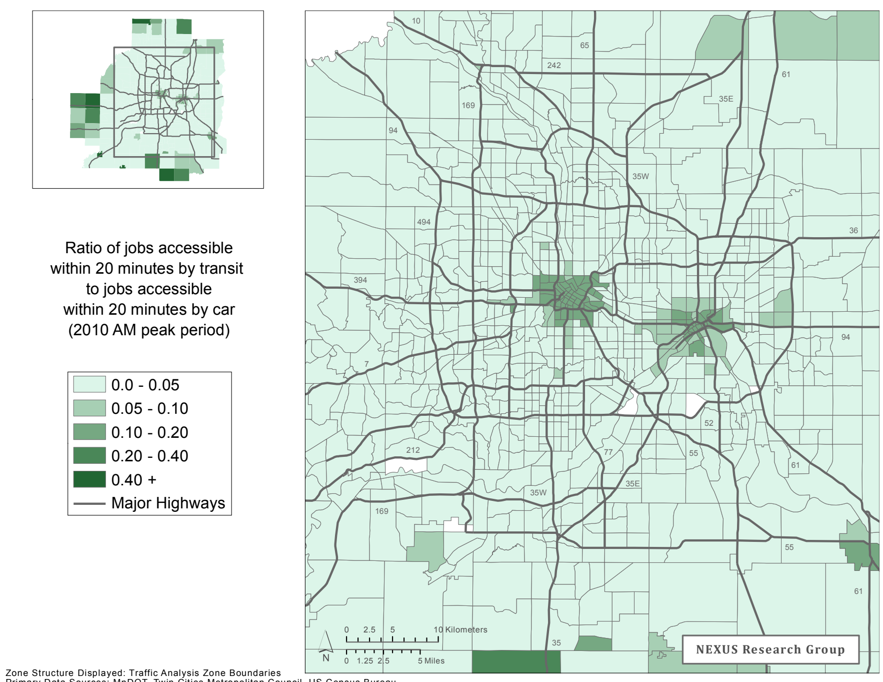

Figure 4.12: Ratio of 20-minute accessibility to jobs by transit to 20-minute accessibility to jobs by auto (2010 AM peak period)

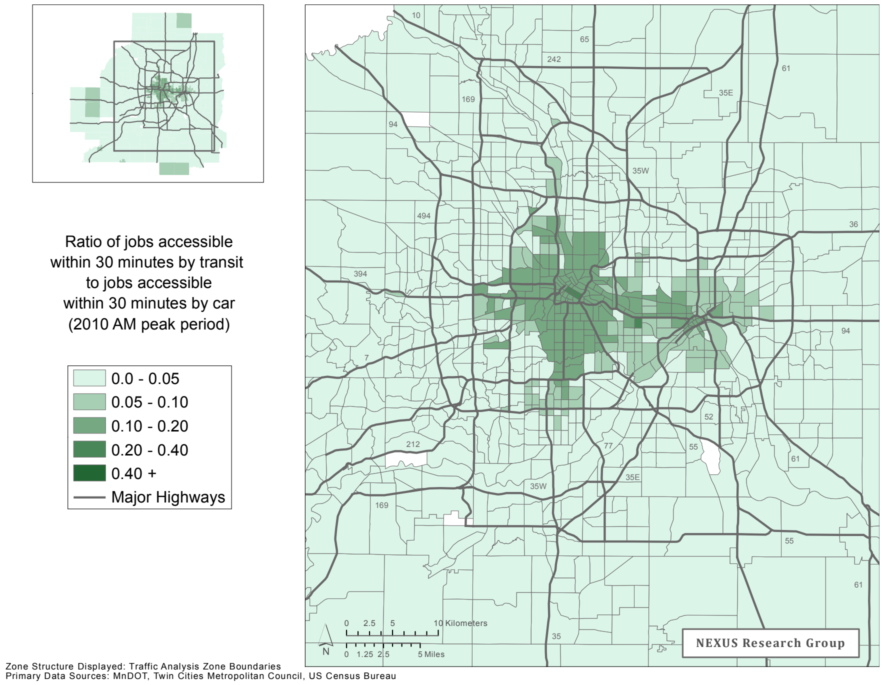

Figure 4.13: Ratio of 30-minute accessibility to jobs by transit to 30-minute accessibility to jobs by auto (2010 AM peak period)

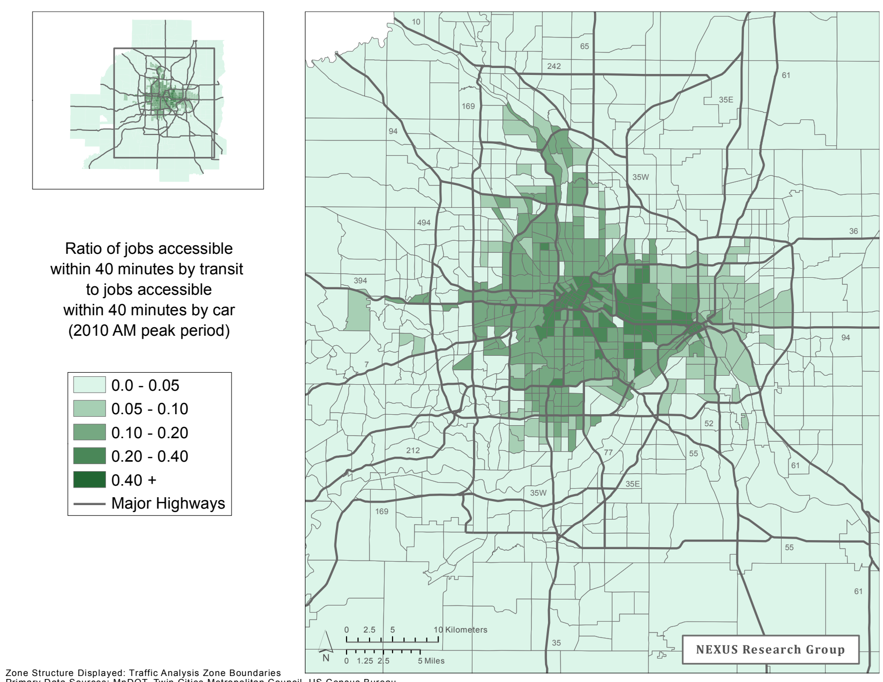

Figure 4.14: Ratio of 40-minute accessibility to jobs by transit to 40-minute accessibility to jobs by auto, (2010 AM peak period)

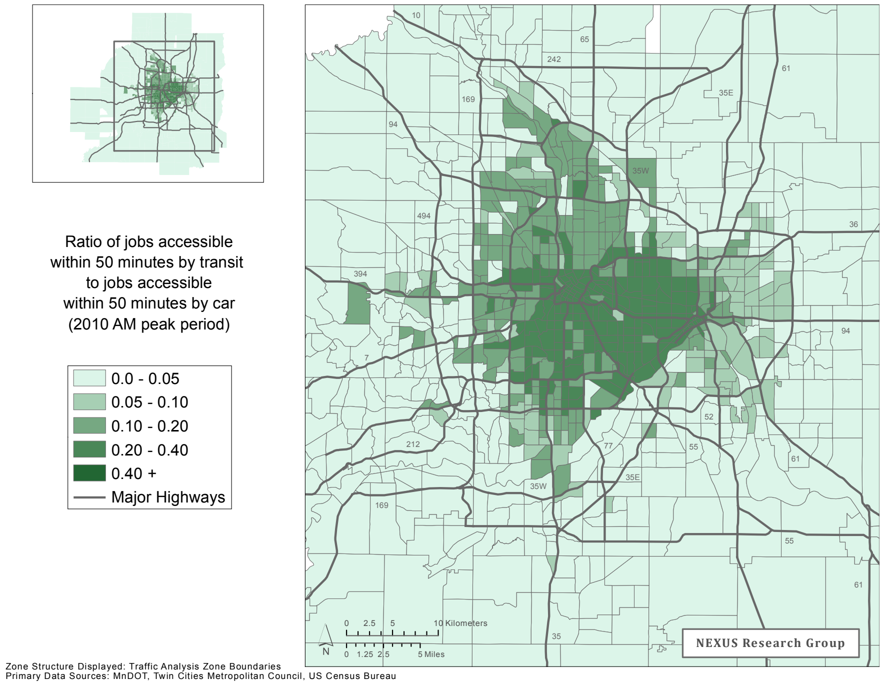

Figure 4.15: Ratio of 50-minute accessibility to jobs by transit to 50-minute accessibility to jobs by auto, (2010 AM peak period)

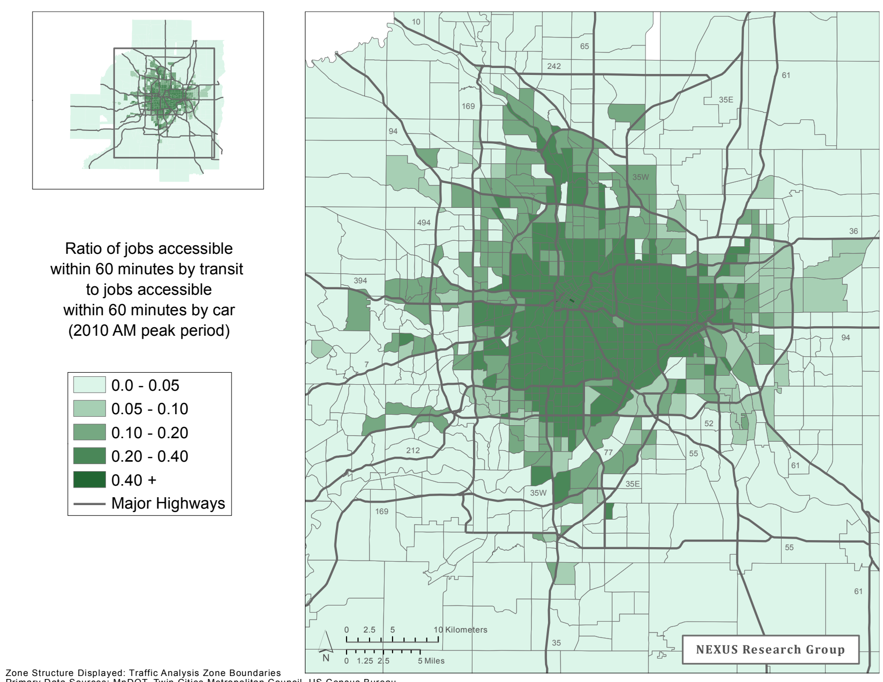

Figure 4.16: Ratio of 60-minute accessibility to jobs by transit to 60-minute accessibility to jobs by auto, (2010 AM peak period)

Chapter 5

Ongoing Implementation

5.1 Overview of Tasks

5.1.1 Preparing Land Use Data

- **Estimated labor time:** 4 hours
- **Estimated total time:** 4 hours
- **Estimated cost:** None (assuming publicly-available data sources)

For use in accessibility evaluation, land use data must be represented at the appropriate geographic level and associated with the relevant geographic units. In most cases, land use data will already exist in a spatial dataset such as a geodatabase or shapefile. Examples include LEHD, ACS, and other Census-based data sources which provide data linked to Census-defined geographic identifiers. The process described in this report can evaluate accessibility to any type of opportunity that can be represented at the TAZ level.

The goal of land use data preparation is to make sure the land use data are in a format which can be incorporated into the rest of the evaluation process. The level of effort required will depend on the format of the original data and the amount of processing required to fit the guidelines provided in Appendix B. In general, data from sources such as LEHD and ACS can be prepared for accessibility evaluation use in 2–4 hours.

5.1.2 Calculating Auto Speeds

- **Estimated labor time:** 4 hours
- **Estimated total time:** 24 hours
- **Estimated cost:** If commercial GPS speed sources are used, price is negotiated with vendor.

Freeway speeds are calculated, using MNFSpeedCalc, from loop detector measurements available from MnDOT and the MTO. This calculation involves a very large amount of data and can take as much as 24 hours to complete. Once the calculation is started no user interaction is required. The result is a set of average speeds for each detector for a specified time period of the day.

GPS-based speeds require no calculation but must be attached to the appropriate links in the model network. The GPS speeds used in the evaluation described in this report, which were collected during a 2008 survey, are already assigned to the appropriate links and are included in the model network delivered with this report.

5.1.3 Calculating Auto Travel Times

- **Estimated labor time:** 6 hours
- **Estimated total time:** 8 hours
- **Estimated cost:** None (assuming ArcGIS and Network Analyst are available)

Speeds must be assigned to the appropriate links in the model network based on the locations of detectors and stations. The model network delivered with this report includes detector station-link associations for detector stations which existed in 2010. Using these associations, speed assignments can be performed in 4–6 hours using standard GIS join operations. Once speeds are assigned to the network, a travel time matrix is calculated using the ArcGIS Network Analyst extension. This calculation takes approximately 1–2 hours depending on processing power.

5.1.4 Calculating Transit Travel Times

- **Estimated labor time:** 2 hours
- **Estimated total time:** 12 hours
- **Estimated cost:** None

Transit travel times are calculated using a Java command-line tool which takes its input from a GTFS file. This calculation can take as much as 12 hours, though computers with multiple processors can take advantage of parallelization to significantly reduce this time. Once the calculation is started no user interaction is required. The result is a travel time matrix formatted for use in accessibility calculations.

5.1.5 Calculating Accessibility

- **Estimated labor time:** 2 hours
- **Estimated total time:** 4 hours

- **Estimated cost:** None

Finally, accessibility calculation is performed in ArcGIS using the Cumulative Opportunities Accessibility tool. It combines one or more land use tables with one or more travel time tables to produce cumulative opportunity accessibility tables at each time threshold between 0 and 60 minutes in increments of 5 minutes. The calculation time depends on the number of input tables; for a single pair of tables, calculation time is less than 1 hour. Most systemwide evaluations will require processing several pairs of input tables.

5.2 Detailed Procedures

Detailed procedures for implementing an evaluation of accessibility are provided in the Appendix. Table 5.1 lists the references for each task.

Table 5.1: References to detailed task procedures

Location	Topic
Appendix B	Data Format Conventions
Appendix C	Preparing Land Use Data
Appendix D	Calculating Auto Speeds
Appendix E	Calculating Auto Travel Times
Appendix F	Calculating Transit Travel Times
Appendix G	Calculating Accessibility

These procedures include step-by-step instructions for using the various software tools developed over the course of the Access to Destinations project. They assume proficiency with ArcGIS 10 and its Network Analyst extension. In particular, users should be able to:

- Create and manage file geodatabases
- Use toolboxes and tools
- Import tables from various formats into file geodatabases
- Join tables and feature classes based on attributes and spatial relationships
- Create new fields in tables and feature classes
- Calculate field values based on other fields
- Create network datasets from feature classes and shapefiles

- Create and solve OD cost matrix layers using Network Analyst

When these operations are necessary, the procedures detailed in the Appendix will describe their parameters and application, but in general will not provide step-by-step instructions.

5.3 Maintenance

The following items will require updates and other maintenance:

- **Model Network**

  The accessibility evaluation process described in this report relies on the model network maintained by the Metropolitan Council to provide a representation of the regional road network down to the arterial level. The current version of the model network was completed in 2009, and therefore provides a reasonably accurate representation of the state of the road network in 2010. Future evaluations of accessibility must ensure that the network used for evaluation is reasonably accurate for the time period of study.

  Additionally, updates to the model network may require additional work to make them useful to future evaluations of accessibility. The current evaluation process depends on specific features of the current version of the model network, such as link IDs and link directionality. If these change in future versions of the model network, this process will require adaptation.

- **Detector/Link Mapping**

  The version of the model network delivered with this report has detector stations which existed as of 2010 associated with the appropriate link in the model network. However, both the network and the locations of detectors will likely change in the future. The Metropolitan Council is currently preparing a revised model network based on 2010 TAZ geography, and MnDOT adds, removes, and alters detector installations as necessary during highway construction and maintenance. Future evaluations of accessibility which rely on loop detector data must ensure that each detector station can be accurately associated with the correct link in the model network.

5.4 Potential Refinements

5.4.1 OpenTripPlanner Analyst

OpenTripPlanner (OTP) is an open-source software project begun in 2009 by OpenPlans with the goal of creating a system for providing multi-modal travel routing using publicly-available data sources. It relies on road network data from OpenStreetMap (OSM) and GTFS feeds to provide walking, bicycling, and transit routing. OTP is currently deployed in six North American cities including New York, Washington DC, and Portland. More information can be found at http://opentripplanner.com.

In July 2012, OTP announced a new Analyst module for their software. Earlier versions of OTP provided shortest-path routing queries only between individually-specified origin and destination pairs, making it unsuitable for use in large-scale accessibility evaluation. However, OTP Analyst is designed from the ground up to find full shortest-path matrices, and can include land use information to provide accessibility calculations with no additional processing. With this extension, it is possible to use OTP Analyst to calculate transit travel times and accessibility in a manner suitable for use in accessibility evaluation.

Compared to the Nexus Transit Travel Time Calculator, OTP Analyst offers both advantages and disadvantages. OTP Analyst is a significantly larger and more complex software system which must be appropriately configured for each deployment. While this increases implementation cost, it also provides a more flexible set of parameters which can accommodate a wider range of assumptions about traveller behavior. OTPs increasingly widespread adoption makes it more responsive when issues are discovered or new features are needed. Both pieces of software are open source.

One of the most promising attributes of OTP Analyst, however, is not yet fully realized. It is capable of calculating routes and accessibility by auto as well as by transit, walking, and biking, but this use is currently limited by two factors. First, OTP relies on road network data from OpenStreetMap, a publicly-editable database of road and other transportation geometry. This database was initially seeded with TIGER road centerline data, and has been significantly enhanced over several years by user-submitted GPS traces. Anecdotally, OSMs geographic coverage and accuracy is impressive and rivals or exceeds that of commercial datasets. However, it also varies from city to city with user participation. In general, OSM (and by extension OTP) has not been analyzed as a potential data source for transportation planning uses.

Second, OTP has no publicly-available data source from which it can draw speed information. Speeds calculated from loop detector data or collected by GPS sensors could be attached to the OSM network; however, the process of conflating data between two geographic data sources is generally labor-intensive.

OpenPlans status as a non-profit focused on publicly-accessible data sources make it unlikely that they will direct significant effort towards accommodating commercially-available speed data, or data for which no generally recognized standard exists. However, OTPs open source license enables users and organizations to make their own modifications, offering the possibility that in the future, OTP Analyst could be used as a single comprehensive system for multi-modal accessibility evaluation. Future evaluations of accessibility should revisit OTP Analyst to determine if it has become a more appropriate tool.

5.4.2 GPS-Based Speeds

The calculation and processing of freeway and arterial travel times is by a wide margin the most labor- and computation-intensive part of the evaluation process described here. The rapidly increasing availability of GPS-based speed measurements offers an appealing alternative. Companies such as INRIX, NavTeq, and TomTom sell datasets or data subscriptions which include speed measurements aggregated from samples of very large numbers of GPS device users.

These data sources have the potential to dramatically simplify the calculation of auto travel times. In addition to straightforward computational savings, GPS-based speed sources can provide consistency across different types of road links. Earlier phases of the Access to Destinations project use a multitude of different sources for speeds, and while the implementation described in this report simplifies the situation considerably, it still relies on speeds recorded by two fundamentally different technologies—loop detectors and GPS sensors (Section 4.2.2). A sufficiently robust GPS-based source, validated against speeds measured by loop detectors, could provide speed data for both freeway and arterial links. This would simplify the overall evaluation process and reduce the number of data source-specific methodological differences and assumptions which can influence the final results.

Earlier stages of this process had anticipated the use of GPS-based speed data purchased from TomTom by the Metropolitan Council. At the time of this writing, the Council has acquired the raw data and is in the process of conflating speed measurement data points to links in the model network. The dataset as provided by TomTom has a spatial structure derived from the underlying GPS traces rather than any established road alignments. This work is proceeding alongside the creation of a new model network that supports the use of 2010 TAZ definitions (Section 4.2.3).

5.4.3 Time-Averaged Transit Accessibility

The current version of the Nexus Transit Travel Time Calculator provides what can be thought of as "best-case" transit travel times: it evaluates all available departures during a specified analysis period, and selects the departure that provides the shortest travel time—and therefore the greatest accessibility. Effectively, it assumes that transit riders' personal schedules are infinitely flexible, and that riders choose departure times to minimize trip time, rather than to match specific desired departure or arrival times. The transit routing algorithms used by OpenTripPlanner, described above, have the same limitations.

A slightly more accurate representation of transit accessibility over a time period could be achieved by averaging the travel times provided by all departures during that period, and this would be a relatively straightforward modification to the current method. However, this type of averaging would have effects of different magnitudes at stops with different headway patterns, and it still assumes that riders incur no disutility when trips do not depart or arrive at their desired times. A more thorough evaluation of transit accessibility could incorporate the costs in "lost time" experienced by transit users while waiting for a trip to depart, or after arriving earlier than desired. [19]

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Appendix A

Equations

A.1 Cumulative Opportunities Accessibility

$$A_{i,co} = \sum_{j=1}^{n} O_j f\left(C_{ij}\right) \tag{A.1}$$

$A_{i,co}$ = cumulative opportunities accessibility from a zone (i) to the considered type of opportunities

O_j = number of opportunities of the considered type in zone j (e.g., employment, shopping, etc.)

C_{ij} = generalized (or real) time or cost of travel from i to j

$f\left(C_{ij}\right)$ = impedance function

Using the cumulative opportunities measure, $f\left(C_{ij}\right)$ is defined as 1 if $C_{ij} < T$ and 0 otherwise. T is the travel time threshold for which we will compute the number of activities that can be reached.

A.2 Weighted Opportunities Accessibility

Weighted opportunities accessibility uses the same generalized equation as the cumulative opportunities measure but provides a different definition for the impedance function. Common definitions include gravity-based functions (A.2) and negative exponential functions (A.3).

$$A_{i,gw} = \sum_{j=1}^{n} O_j {C_{ij}}^{-2} \tag{A.2}$$

$$A_{i,ew} = \sum_{j=1}^{n} O_j \exp\left(\theta C_{ij}\right) \tag{A.3}$$

A.3 Person-Weighted Accessibility

Person-weighted accessibility is the weighted average of accessibility by zone, where the weight is the population (e.g., the number of workers) in that zone experiencing that level of accessibility. This can be computed for the entire region or any sub-region.

$$A_{pw} = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} P_i} \tag{A.4}$$

A_{pw} = person-weighted average accessibility of all subzones

P_i = population in subzone i

A.4 Combining Accessibility Across Modes

$$A_{i,um} = \sum_{j} \sum_{m} O_j f\left(C_{ijm}\right) \tag{A.5}$$

or

$$A_{i,wm} \; = \; \sum_{j} \sum_{m} O_j M_{ij} f\left(C_{ijm}\right) \tag{A.6}$$

$A_{i,um}$ = unweighted cross-modal accessibility from zone i to the considered type of opportunities j

$A_{i,wm}$ = weighted cross-modal accessibility from zone i to the considered type of opportunities j

C_{ijm} = cost of travel from i to j by mode m

M_{ijm} = share of mode m in trips from i to j (0–1)

Appendix B

Data Format Conventions

B.1 File and Table Names

Names for files and tables containing input data and calculation results are composed by combining elements which describe their contents. The possible components are:

Type Describes the general type of information contained in the table. The type can be:

- `lu` for land use data such as job counts or population,
- `tt` for travel time data, or
- `acc` for accessibility data.

Subject Describes the particular subject of a land use or accessibility data file, as well as the year for which the data is applicable. For example, a subject of `jobs2010` indicates data describing job counts for the year 2010, while `pop2005` indicates data describing population for the year 2005.

Mode Describes the transportation mode of interest in a travel time or accessibility data file, as well as the time of day and year for which the data is applicable. For example, a mode of `autoAM2010` indicates data describing auto travel times in the AM peak period for 2010, while `transitPM2005` indicates data describing transit travel times for the PM peak period for 2005.

Scale Describes the geographic scale at which the data are represented, and the Census year on which the geometry is based (if applicable). For example, a scale of `block2000` indicates data represented at the block level using Census 2000 definitions, `bgroup2010` indicates data represented at the block group level using Census 2010 definitions, and `taz2000` indicates data represented at the TAZ level using TAZ definitions based on Census 2000 geometry.

Land use tables require type, subject, and scale codes; travel time tables require type, mode, and scale codes; and accessibility tables require type, subject, mode, and scale codes. Codes are joined by underscores. For example:

`lu_jobs2010_block2010` indicates a table containing jobs counts in 2010 for each Census 2010 block.

`tt_transitAM2010_taz2000` indicates a table containing travel times by transit during the AM peak period in 2010 between TAZs based on Census 2000 geometry.

`acc_jobs2010_transitAM2010_taz2000` indicates a table containing accessibility to jobs counted in 2010, using transit travel times during the AM peak period in 2010, for TAZs based on Census 2000 geometry.

B.2 Table Field Names

When working within ArcGIS, every table will have an additional, automatically-generated field named `OBJECTID`. This field is not used for accessibility calculation and is omitted below.

B.2.1 Land Use Tables

Land use tables have two fields:

`[scale]` The value of [scale] is determined by the geographic scale at which the data is represented. This should match the scale code used in the table name as described in Section B.1, with the year removed. The contents of this field are represented using a **string** or **text** data type.

`n[subject]` The value of [subject] is determined by the subject which the data describes. This should match the subject code used in the table name as described in Section B.1, with n prepended. The contents of this field are represented using an **integer** or **floating-point** data type as appropriate.

For example, the table `lu_jobs2010_block2010` would have the fields `block` and `njobs`.

B.2.2 Travel Time Tables

Travel time tables have three fields:

`o[scale]` The value of [scale] is determined by the geographic scale at which the data is represented. This should match the scale code used in the table name as described in Section B.1, with the year removed and o prepended to indicate origin. The contents of this field are represented using a **string** or **text** data type.

`d[scale]` The value of [scale] is determined by the geographic scale at which the data is represented. This should match the scale code used in the table name as described in Section B.1, with the year removed and d prepended to indicate destination. The contents of this field are represented using a **string** or **text** data type.

`mins` The contents of this field are represented using a **floating-point** data type, and represent the travel time in minutes between from an origin to a destination.

For example, the table `tt_transitAM2010_taz2000` would have the fields `otaz`, `dtaz`, and `mins`. In each row, `mins` would indicate the travel time in minutes from `otaz` to `dtaz`.

B.2.3 Accessibility Tables

Accessibility tables have thirteen fields:

`[scale]` determined by the geographic scale at which the data is represented. This should match the scale code used in the table name as described above, with the year removed. The contents of this field are represented using a string or text data type.

`t5`, `t10`, `t15 ...  t60` represent cumulative opportunities accessibility at 5-minute threshold increments between 5 and 60 minutes. The contents of these fields are represented using an integer or floating-point data type as appropriate.

Appendix C

Preparing Land Use Data

C.1 Overview

For use with the Cumulative Opportunities Accessibility Tool, land use data must be in the proper format, as described in Appendix B.

C.2 Inputs

The format of input datasets can vary widely depending on their source. Any data source which can be converted to meet the guidelines described in Appendix B can be used.

C.3 Procedure

1. Save the original land use data file in a format readable by ArcGIS (CSV, DBF, Excel, *etc*).
2. If necessary, use ArcGIS tools to aggregate, disaggregate, or convert the original land use data to the appropriate geographic level.
3. In ArcGIS 10, create or choose a File Geodatabase to hold the land use data.
4. Using the Table to Table tool in the Conversion toolbox, transfer the land use data table to the selected geodatabase. Using the guidelines in Appendix B, remove and rename fields as necessary and appropriate name for the data table.

Appendix D

Calculating Auto Speeds

D.1 Overview

Loop detector data files store volume and occupancy information at 30-second intervals for each detector in the metropolitan area. This data must be converted to speeds for use in travel time calculation. The Nexus Freeway Speed Calculator (NexusFSCalc) performs this calculation.

NexusFSCalc is implemented in Python; it will run on any operating system where Python version 2.7 is available. To verify availability, run the command `python --version` at a command prompt. If Python is not installed or a version other than 2.7 is reported, install or upgrade Python before continuing.

NexusFSCalc requires the inputs described below. Because of their large size, .traffic files are not included in the data archive delivered with this report. They are available from MnDOT and the MTO.

This calculation can take 12 hours or more to complete, depending on processing power. The calculation requires a large amount of memory; it was tested on computers with 8GB of memory. It may be possible to perform the calculation with less memory available, but processing times will be significantly lengthened.

Speeds from GPS-based data sources require no calculation but must be assigned to the appropriate model network links as described in Appendix E.

D.2 Inputs

- **Loop Detector Data**

  Loop detector data is stored in .traffic files—one file for each day. Files are named based on the day they represent: for example, the file `20100312.traffic` contains the loop detector data for March 12, 2010. NexusFSCalc assumes that all .traffic files retain their original name and that they are stored in a single directory. Before using NexusFSCalc, collect the necessary .traffic files and note their location.

- `metro_config.xml` File

  The speed calculation methods used in NexusFSCalc require information about the structure of the freeway network and the relationships between detectors and stations. This information is provided by the `metro_config.xml` file used by the IRIS project. A copy of this file from an appropriate time period is necessary.

D.3 Procedure

1. Choose the appropriate program parameters.

   `-d [directory]`

   Look for .traffic files in the specified directory.

`-y [year]`

Process .traffic files for the specified year.

`-m [metro_config.xml file]`

Load detector and station location information from the specified file. This file must be in the format of an IRIS metro_config.xml file.

`-s [start time]`

Start time of day, in hours (e.g. 7 AM = 7, 4P M = 16).

`-e [end time]`

End time of day, in hours (e.g. 9 AM = 9, 6 PM = 18).

`-o [output file]`

Write the output speed table to the specified file.

2. Finally, execute the program with the selected parameters. For example, the command

```
python NexusFSCalc.py -d data_dir -y 2010 -m metro_config.xml -s 7 -e 9
     -o station_speeds.csv
```

will look in the `data_dir` subdirectory and load detector data from all .traffic files beginning with `2010`, then calculate the average weekday speeds between 7 AM and 9 AM and write the results to the file `station_speeds.csv`.

Appendix E

Calculating Auto Travel Times

E.1 Overview

A TAZ-level travel time matrix is calculated using the Network Analyst extension for ArcGIS 10. The structure of the network is defined by the Metropolitan Council's model network released in 2009, and link speeds are derived from GPS and loop detector data sources.

Calculation of link speeds from loop detector data is described in Appendix D. It is assumed that speeds from GPS-based data sources are associated with link IDs that are compatible with the current model network.

E.2 Inputs

- **Road Network** The road network structure is defined by the Metropolitan Councils 2009 model network. A shapefile containing this dataset is included in the data archive delivered with this report.
- **Link Speeds** Link speeds are derived from GPS and loop detector data sources. Appendix D describes the preparation of link speed tables for each speed source. These tables will be joined to the model network.
- **Origins and Destinations (TAZs)** The ArcGIS Network Analyst requires sets of points to use as origins and destinations for travel time calculations. The model network is designed to use TAZ centroids as origins and destinations, so this procedure requires a shapefile or feature class representing the centroids of TAZs with an appropriate ID field.

E.3 Procedure

E.3.1 Assigning Speeds to Network Links

Link speeds are drawn from two independent sources: GPS measurements and loop detector measurements. Also, a default speed of 23 mph is used for the dummy links which connect TAZ centroids to the arterial network; these are an abstract representation of local streets. It is critical that the correct speed source is used for each link in the model network.

First, the GPS and loop detector speeds must be joined to the network links:

1. Open the model network shapefile, the GPS speed table, and the loop detector station speed table in ArcGIS 10.
2. Join the GPS speed table to the network shapefile by the `ID` field.
3. Join the loop detector station speed table to the network shapefile by the `SID` field (station ID).

Next, for each link the correct data source must be selected and stored in a common field:

1. Add a new field of data type double which will store the final selected speed for each link. The name of the field should indicate the year and time period for which the speeds will apply: for example, the field `s2010am` could contain speeds for the AM peak period in 2010.

2. Store the final speeds for centroid connector links:

   - Using the Select by Attributes tool, select all links where the `ASGNGRP` field is 9. These are abstract links connecting TAZ centroids to the arterial network.
   - With these links selected, use the Field Calculator tool to set the value of the final speed field to 23.

3. Store the final speeds for freeway links where loop detector speeds are available:

   - Using the Select by Attributes tool, select all links where the `detspeed` field is not `NULL`. These are links which have valid speeds calculated from loop detector data.
   - With these links selected, use the Field Calculator tool to set the value of the final speed field to the value of the loop detector speeds field.

4. Store the final speeds for all other links using GPS-based speeds:

   - Using the Select by Attributes tool, select all links where the final speed field is `NULL`. These are links which did not receive the default centroid connector speed or speeds from loop detector data.
   - With these links selected, use the Field Calculator tool to set the value of the final speed field to the value of the GPS speed field.

5. Using the Select by Attributes tool, confirm that there are no links where the final speed field is `NULL`.

Finally, the final link speeds must be converted to link traversal times for use in travel time calculation:

1. Add a new field of data type double which will store the traversal time for each link. The name of the field should indicate the year and time period for which the speeds will apply: for example, the field `t2010am` could contain speeds for the AM peak period in 2010.

2. Use the Field Calculator tool to calculate link traversal times based on link speeds and lengths (stored in the `LENGTH_MI` field). Link lengths are in miles and speeds are in miles per hour, and the final travel time for each link should be represented in minutes.

E.3.2 Calculating the Travel Time Matrix

After an appropriate traversal time is assigned to each link in the model network, it can be used to construct a network dataset and calculate a travel time matrix.

1. Use the New Network Dataset wizard to construct a new network dataset from the model network using the following parameters:
   - Do not model turns
   - Endpoint connectivity
   - Do not model elevation
   - Use the default Oneway restriction attribute
   - Add a new attribute Minutes with usage type Cost, units Minutes, and data type Double. Associate it with the travel time field.
   - Do not establish driving directions
2. Use the Network Analyst toolbar to create a new OD Cost Matrix targeting the model network dataset.
3. Set the parameters of the OD Cost Matrix as follows:
   - Use the Minutes attribute as the impedance.
   - Set Output Shape Type to None
   - Add the Minutes attribute as an accumulation attribute
4. Load the TAZ centroid shapefile or feature class as the origins for the OD Cost Matrix.
   - Use the TAZ id field as the sort field
   - Use the TAZ id fild as the name
5. Load the TAZ centroid shapefile or feature class as the destinations for the OD Cost Matrix.
   - Use the TAZ id field as the sort field
   - Use the TAZ id fild as the name
6. Solve the OD Cost Matrix.
7. Export the calculated routes layer of the OD Cost Matrix to a new table. Name the file and add, remove, and modify fields to match the guidelines in Appendix B.

Appendix F

Calculating Transit Travel Times

F.1 Overview

Calculation of transit travel times is performed using the Nexus Transit Travel Time Calculator (NexusTTTCalc). NexusTTTCalc is a command-line tool implemented in Java; it will run on any operating system where the Java Runtime Environment (JRE) version 1.5 or higher is available. To verify availability, run the command `java -version` at a command prompt. If the JRE is not installed or a version earlier than 1.5 is reported, install or upgrade the JRE before continuing.

NexusTTTCalc requires three input files, described below. The data archive delivered with this report contains the files necessary for calculating transit travel times in for 2010 using 2000 block definitions and 2000 TAZ definitions. For other years and geographies, appropriate input files can be obtained from transit providers and generated using standard GIS techniques.

For the 2010 transit schedule, this calculation can take 12 hours or more to complete, depending on processing power. On computers with more than one processor, multithreaded processing can significantly reduce calculation time. This calculation also requires a large amount of memory; it was tested on computers with 8GB of memory. It may be possible to perform the calculation with less memory available, but processing times will be significantly lengthened.

F.2 Inputs

Transit travel time calculation requires three input files. These files can have any name, but their contents must be as follows.

- **GTFS file**

  This must be a valid GTFS file. Typically these are provided by transit operators such as Metro Transit. A description of the GTFS format can be found at https://developers.google.com/transit/gtfs/reference.

- **TAZ file**

  This must be a CSV file providing IDs and coordinates of TAZs. The results of the transit travel time calculation will be reported using these identifiers. The file must contain the following fields, in this order:

  `ID` A string uniquely identifying each Transportation Analysis Zone.

  `LAT` A floating-point number identifying the latitude of the TAZs centroid, in the WGS84 coordinate system.

  `LON` A floating-point number identifying the longitude of the TAZs centroid, in the WGS84 coordinate system.

- **Block file**

  This must be a CSV file providing IDs and coordinates of Census blocks, as well as the ID of the TAZ containing each block. The file must contain the following fields, in this order:

  `GEOID` A string uniquely identifying each Census block.

  `TAZ` A string identifying which TAZ contains each block. This must match an entry in the TAZ file.

  `LAT` A floating-point number identifying the latitude of the blocks centroid, in the WGS84 coordinate system.

  `LON` A floating-point number identifying the longitude of the blocks centroid, in the WGS84 coordinate system.

F.3 Procedure

1. Locate or create the necessary input files described above, and note their file names.
2. Choose the appropriate program parameters. Parameters not marked optional are required.

   `-g [GTFS file]`

   Read schedule information from the specified GTFS file.

   `-id [service id]`

   The service ID to process. This must match a service ID in the calendar.txt file of the specified GTFS file. Only one service ID can be processed at a time.

   `-p [block file]`

   Read block information from the specified file.

   `-r [TAZ file]`

   Read region information from the specified file.

   `-o [output file]`

   Write the output matrix to the specified file.

   `-s #`

   Start time of day, in seconds past midnight (e.g. 7AM = 25200). Trips which depart before this time will not be included in travel time calculations.

   `-e #`

   End time of day, in seconds past midnight (e.g. 9AM = 32400). Trips which depart after this time will not be included in travel time calculations.

-b #

(Optional) The maximum number of boardings. 0 will allow walking trips only; 1 will allow a single boarding and no transfers; 2 will allow a single transfer; etc. The default is 2.

-w #

(Optional) The maximum allowable wait time for transfers, in seconds. Potential transfer trips which depart later than the current time plus this value will be ignored. The default is 900 seconds (15 minutes).

-mp #

(Optional) The maximum number of concurrent threads. The default is 1 (single-threaded operation).

3. Execute the program with the selected parameters. For example, the command

```
java -Xmx4G -jar NexusTTTCalc -g gtfsfile.zip -p blocks.csv -r TAZ.csv -id weekday
     -s 25200 -e 32400 -o results.csv
```

will calculate transit travel times using the schedule stored in `gtfsfile.zip` and labeled with service ID weekday, between 7 AM and 9 AM. Travel times will be calculated between the Census blocks identified in `blocks.csv` and then averaged to the TAZs identified in `TAZ.csv`. Trips will be capped at 2 boardings with a maximum transfer waiting time of 900 seconds (the default values). The result will be written to the file `output.csv`.

Appendix G

Calculating Accessibility

G.1 Overview

Accessibility calculations are performed using the *Cumulative Opportunities Accessibility tool*, which runs within ArcGIS 10. This tool is designed to read travel time and land use information formatted according to Appendix B, and writes its output using the same format guidelines.

G.2 Inputs

The Cumulative Opportunity Accessibility tool requires a minimum of two inputs: a single land use table and a single travel time table. To facilitate the easy calculation of accessibility to multiple types of destinations and/or by multiple modes, additional land use and travel time tables can be specified. The tool will create one accessibility table for each pair of land use and travel time tables.

G.3 Procedure

1. In ArcGIS 10, locate the Accessibility Tools toolbox and launch the Cumulative Opportunities Accessibility tool within it.
2. In the Travel Time Tables section, add one or more travel time tables.
   - Each travel time tables name and contents must follow the guidelines described in Appendix B.
   - All travel time tables must use the same geographic scale.
3. In the Land Use Tables section, add one or more land use tables.
   - Each land use tables name and contents must follow the guidelines described in Appendix B.
   - All land use tables must use the same geographic scale, and it must be the same scale used for the travel time tables.
4. In the Output Workspace field, select a location to store the results.
5. Click OK. The tool will individually combine each specified travel time table with each specified land use table. For each pair, it will calculate an accessibility table and store the result in the output workspace specified.
6. The output accessibility tables can be joined to a shapefile or feature class using the geometry ID field for use in mapping.