Measuring Accessibility by Automobile

Report # 11 in the series

Access to Destinations Study

Report # 2010-09

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16. Abstract (Limit: 250 words)

This study describes the development and application of a set of accessibility measures for the Twin Cities region that measure accessibility by the automobile mode over the period from 1995 to 2005. In contrast to previous attempts to measure accessibility this study uses travel time estimates derived, to the extent possible, from actual observations of network performance by time of day. A set of cumulative opportunity measures are computed with transportation analysis zones (TAZs) as the unit of analysis for the years 1995, 2000 and 2005. Analysis of the changes in accessibility by location over the period of study reveals that, for the majority of locations in the region, accessibility increased between 1995 and 2005, though the increases were not uniform. A “flattening" or convergence of levels of accessibility across locations was observed over time, with faster-growing suburban locations gaining the most in terms of employment accessibility. An effort to decompose the causes of changes in accessibility into components related to transportation network structure and land use (opportunity location) reveal that both causes make a contribution to increasing accessibility, though the effects of changes to the transportation network tend to be more location-specific. Overall, the results of the study demonstrate the feasibility and relevance of using accessibility as a key performance measure to describe the regional transportation system.

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Access to Destinations, Phase 3: Measuring Accessibility by Automobile

Final Report

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Executive Summary

The purpose of the Access to Destinations study is to create a metric of accessibility for the seven-county Twin Cities metropolitan area. This phase of the study is concentrated on determining the number of opportunities accessible by automobile from points of reference across the region.

This study uniquely generates accessibility measures that take as inputs a matrix of origin-destination (O-D) travel times for the region that are derived from actual traffic data, rather than relying on modeled zone-to-zone travel times. To that effect, several sources of traffic volume data and link travel time estimates are employed. The components of the travel time matrix include freeway travel time estimates, freeway ramp delay estimates, and arterial travel time estimates. For the most part, freeway travel-time data were collected from freeway loop detector data, ramp delays were modeled using observed traffic counts and a stochastic queueing model, and arterial travel-time estimations are generated from estimated traffic levels, calibrated with counts from Automatic Traffic Recorders (ATR), and applied to a locally calibrated link performance function. The land use data combines Census data, Longitudinal Employer-Household Dynamics (LEHD) employment records, and Metropolitan Council estimates for the number of jobs, persons, and households.

Taken by itself, the travel time matrix generated above measures *mobility*. The information it contains is enough to determine the speed at which network users can travel from any analysis zone to any other. Weighting *mobility* by the number of opportunities it presents to arrive at *accessibility*. Accessibility can be thought of as the potential opportunity for interaction. In this analysis, cumulative opportunity measures are calculated as total numbers of jobs, residents and workers reachable from each point in a given time period. This measure was chosen because it is spatially continuous and suitable for creating maps to compare changes in accessibility across the region.

The most striking trend one notices when examining changes in accessibility from 1995 to 2005 is that in fact, accessibility by automobile increases almost everywhere over this period for the larger timebands. Examination of the contribution of changes of both land use and transportation show that the change in land use and the densification of activities offset any increase in congestion in this period. While in 1995 only one traffic analysis zone could reach more than one million jobs within 20 minutes, by 2005 that number had increased to 20. Within 30 minutes, well more than half the population of the region can reach over one million jobs, while within 45 minutes, almost everyone in the Twin Cities region can reach more than one million jobs by auto. All of this is not to say there were no accessibility losses, as there were some, but they were outweighed by gains.

At short travel time contours, accessibility is concentrated in the urban centers of Minneapolis and St. Paul. As the allowed travel times increase, corridors of relatively high accessibility become evident along major highways, especially I-35W south of downtown Minneapolis. In general, the southern portion of the region has access to more destinations in shorter travel times than the north. Once 40 minutes are allowed for travel, residents of all but the most rural zones have access to at least 100,000 jobs. The least accessible zones are in the southwest corner of the region. Other points of interest due to their effects on accessibility are areas that may be near or adjacent to the mainlines of high-speed routes but some distance away from the nearest onramp. Access to jobs is flatter across the region in the P.M. peak period than the AM, meaning the difference between the points with high and low accessibility is not as great. Also note is that the accessibility gains at the edge of region outweigh those in the center. The suburbs are more accessible in 2005 than they were in 1995, while changes in the already highly accessible center city have been much more modest.

Employment remains much more concentrated than labor. Recognizing, that at the metropolitan level, the number of jobs essentially equals the number of workers, access to jobs is much more highly peaked in city centers than access to labor is (though the peak locations are very close). Over this period, the center of gravity of employment has moved westward (in the south-southwest direction), while the center of gravity of labor has moved less so. Labor has continued to suburbanize, more so in the directions North and South of Minneapolis, and less directly due west. A ratio of jobs to labor (which equals 1.0 at the regional level) shows where job access exceeds labor access, and where the converse is true. Overall the region is becoming more balanced at the longer time bands (though less balanced locally).

Chapter 1

Introduction

The coevolution of transportation and land use is not just an historical phenomenon, it is something we see everyday as households and firms relocate to improve their condition in a changing economic landscape, and as transportation providers restructure and extend transportation networks to better serve their customers. Locators select metropolitan regions to be near activities, things, organizations, and people that are important to them, and they select locations within metropolitan areas for similar reasons, trading off benefits and costs of those locations.

In cities, firms aim to achieve economies of agglomeration and improve productivity and output by locating near customers (other firms and/or households depending on the nature of the firm), suppliers (including their labor force), and even competitors - creating a centripetal force in cities, while trying to reduce costs of land and congestion (which is a centrifugal). Households aim to achieve proximity to their work, shops, and other activities and amenities (also a centripetal force) while simultaneously obtaining more house and lot for the money, producing a centrifugal force on urban regions. This tension between centripetal and centrifugal forces keeps the city from achieving either a maximal density (all activities on a single point) or a minimal densities (all activities spread out evenly across space). However the balance between these two forces changes over time with exogenous changes in other technologies (e.g. communication, finance), demographics (e.g. the relative demand for living space varies by life-cycle), socio-economics (e.g. the income or wealth of consumers), and other preferences (e.g. willingness to commute, time scarcity).

The concept of accessibility allows us to measure the efficiency of the city in its primary role, enabling people to reach other people and things. The concept has been well-described in the literature, and in terms of the measure itself, this research constitutes an application rather than a methodological advance. However, this study differs from previous in one important aspect, we are using measured rather than modeled accessibility. This means the inputs to the maps presented here are the results of measurements of travel times and delay (supplemented by carefully calibrated models where those measurements lack) rather than the outputs of a regional planning model or based on assumptions of travel speeds based on road classification.

This study examines the change in the makeup of accessibility in the Minneapolis-St. Paul, Minnesota (Twin Cities) metropolitan area between 1995 and 2005 and tests whether, playing off the title of the recent Thomas Friedman book *The World is Flat*, the *City is Flatter* than it used to be. The period between 1995 and 2005 saw a number of changes in the Twin Cities. Population and employment rose on the order of 1 percent annually, the economy went through one recession associated with the Dot Com bubble, decline in the stock market, and 9/11, and toward the end of the period fuel prices began their rise (ultimately peaking (to date) in 2008). However this is also a period of relative stability in the transportation network. The Twin Cities Interstate system was essentially complete in 1994, and though some road widenings and non-freeway construction have occurred, these have been relatively minor. There was a relatively sharp increase in traffic in the first part of this period, before a leveling off in the later years. Between 1995 and 2005 we see a larger increase in growth in both jobs and workers in the suburbs than the central cities of Minneapolis and St. Paul.

The purpose of the Access to Destinations study is to create a metric of accessibility for the seven county Twin Cities metropolitan area. Previous phases of the study concentrated on determining the number of opportunities accessible by automobile from points of reference across the region. This phase of the study is concentrated on determining the number of opportunities accessible by automobile from points of reference across the region.

The next section describes the data used in this study for both land use and travel times. A travel time matrix is developed and applied to determine the cumulative number of jobs or workers accessible in a given time band. This is followed by a brief methodology on accessibility. The results highlight maps and numeric analysis underlying those maps. Several series of accessibility maps from years 1995 to 2005 in five minute time period intervals are presented. The resulting accessibility is presented as a series of maps, showing These show cumulative opportunities available across the region, how accessibility across the region changed between the three years studied, and travel time contours from specific reference points. We focus on trends from a series of maps within fewer time bands to examine shifts in accessibility more deeply. Specifically, we will look at key commute times including 15, 20, 25, and 30 minute commute-time thresholds. Later, we will narrow the focus to accessibility in years 1995 and 2005 at the 20 minute commute in an attempt to disentangle the those peculiarities of accessibility associated with different accessibility impacts that may be attributed to land use changes or with changes in the transportation system. The report concludes with implications for policy and the potential for future research in this arena.

Chapter 2

Data

2.1 Introduction

The *Access to Destinations* study has as its objective the measurement of accessibility for the Twin Cities metropolitan area for the years 1995, 2000 and 2005. The set of accessibility measures generated by the study will be unusually broad and detailed in that they will cover four modes, several destination types, and at least three separate points in time. Generating these measures, however, requires multiple years' worth of network and socioeconomic data, all synthesized into a common format.

A unique challenge the study faces is that it also seeks to generate accessibility measures that take as inputs a matrix of origin-destination (O-D) travel times for the region that are derived from actual traffic data, rather than relying on modeled zone-to-zone travel times. To that effect, several sources of traffic volume data and link travel time estimates are employed. The components of the travel time matrix are described in further detail in this section and include freeway travel time estimates, freeway ramp delay estimates, and arterial travel time estimates. For the most part, freeway travel-time data were collected from freeway loop detector data, ramp delays were modeled using an M/D/1 model structure, and arterial travel-time estimations were generated using a combination of the Skabardonis-Dowling model and and Stochastic User Equilibrium (SUE) updated with counts from Automatic Traffic Recorders (ATR). The land use data also requires some explanation, as the number of jobs by zone and population by zone are only measured decennially with the Census, while our time periods include 1995 and 2005, for which estimates must be made.

2.2 Land use data

Data by TAZ for population, employment and labor were needed for each of the three analysis years, but were not available from any one source or at any one level of aggregation. Data sets for 1995, 2000 and 2005 were compiled using U.S. Census results from 1990 and 2000, the U.S. Census Bureau Longitudinal Employer-Household Dynamics (LEHD) program, the Census Transportation Planning Package (CTPP), and Metropolitan Council TAZ data from 1990 and 2000. Total population, employment and labor in the Twin Cities metropolitan area in each of the three

Table 2.1: Regional totals of cumulative opportunity measures in each analysis year.

Year	Population	Employment	Labor
1995	2,465,389	1,449,268	1,199,732
2000	2,642,056	1,603,295	1,422,079
2005	2,663,303	1,554,369	1,408,238

years as compiled from these sources is shown in Table 2.1.

The total employment numbers are similar to those given by the Metropolitan Council for the seven counties in 2000 [6]. The report also discusses a regional decline in the number of jobs after 2000, though it also mentions that by 2005 the region had returned to its peak. A report by the City of Minneapolis does show an increase in both labor and employment form 2000 to 2005, but may only be considering employment of residents of the seven-county area [1].

For 2005, employment and labor were available directly at the block level from the LEHD. A main file contained employment information for workers who both live and work within the metropolitan area, and an auxiliary file included those who commute into the area to work but live outside it. For labor, only those workers living within the metro area were considered. The 2005 population was imputed by assuming the same ratio of population to employment as in 2000.

Employment and population data were available directly for the year 2000. Population came from the census at the block level, and employment came from the Metropolitan Council 2000 TAZ file. Labor statistics were included in the CTPP data at the block group level. Allocation to block level was accomplished by assuming that each block contained the same proportion of the labor in its block group in 2000 as in 2005.

The 1995 block-level population was computed by averaging the totals from the 1990 and 2000 census data. Employment data was available from the Metropolitan Council for both 1990 and 2000 for the 1990 TAZ geography, and averaged to determine 1995 employment. Labor at the block group level for 1995 was calculated by averaging 1990 and 2000 CTPP data. The resulting block-group averages were allocated to blocks using population proportions from 1990 and then aggregated to the TAZ level.

2.3 Freeway Travel Time Estimation

Abundant data on freeway flows are collected by loop detectors installed throughout the Twin Cities freeway network. These data can be used as important inputs to the calculation of freeway travel times. If information on average vehicle length is known, link travel speeds can be computed from single-loop data using volume and occupancy information, and these speeds can be used to produce estimates of link travel times. However, the single-loop data available from the Twin Cities network does not contain information on average vehicle length.

To overcome this limitation, Kwon and Klar [5] developed a procedure for computing average vehicle lengths. Their procedure identifies free-flow conditions and then recursively adjusts the known speed limit to a free-flow speed. The average vehicle length is then obtained for the identified free-flow condition using the adjusted free-flow speed. Speeds can then be computed using the volume, occupancy and vehicle length data. Using data from neighboring stations, travel times can be computed from measured speeds.

The primary weakness of this approach is that the loop detector data on which it relies are often missing. Construction projects, maintenance work, optical fiber communication cuts or other events may cause the interruption of data collection from loops. Patterns of missing data can be random, or can be temporally or spatially consecutive. Kwon and Klar [5] applied several spatial and temporal imputation methods to recover much of the missing loop detector readings dating back to 1994. The imputation methods included temporal linear regression, spatial inference imputation, week-to-week temporal imputation and dynamic time warping methods. These imputation methods achieved a high degree of success in recovering missing data. After applying the imputation methods to the 1994 data, the amount of missing data was reduced from 31.7 percent to 3.9 percent. The amount of overall loop detector data for the 14 years under study that was deemed valid following the imputation procedure increased from 81.7 percent to 98.6 percent.

For the remaining links, Kwon and Klar [5] suggest an alternate method that could be implemented to complete the imputation and improve the count of valid data to 100 percent. They suggest finding a station for which the data is the most similar to the station missing data and using its data for imputation. In this case, the most similar station would have the lowest accumulated RMSE value when comparing data two weeks prior to the date of missing data.

Rather than estimate or impute missing data, gaps remaining after running the procedure were filled using observed data wherever possible. The first source was to check the Mn/DOT Data Extract tool for the availability of any count data not included previously. The next step was to use data from later years, in cases where loop detectors were installed after the analysis period. Some average speeds were unreasonably high, so the detector data were capped at 70 miles per hour for peak hours and 78 miles per hour for off-peak times. Where detector data was never available, observed speeds from a survey conducted by Zhu et al. [8] were used. For that study, participating commuters were given GPS transponders to record the position and speed of their vehicles at preset time intervals. This resulted in a high sample rate for the freeway system, and speed maps were generated from the collected data. The caps on the detector speeds were determined by comparison with these observations. As a last resort, the estimated free-flow travel times provided with the network from the Metropolitan Council were used.

2.4 Freeway Ramp Delay Estimation

In addition to estimates of freeway link travel times, it is valuable to be able to estimate the delay incurred on freeway ramps. During peak periods, freeway links can become congested and spill back onto ramps, generating delays that are not typically accounted for in transportation planning models. In addition, the Twin Cities region makes extensive use of ramp metering to smooth the flow of traffic on mainline freeways links. These additional delays need to be accounted for if the matrix of travel times is to present a reasonably accurate summary of network performance.

Freeway ramp speeds were calculated using Metropolitan Council free-flow travel times augmented with estimated delays for ramps with meters. Information obtained from Mn/DOT was used to determine which ramps were metered and the times during which the meters were in operation.[1] An M/D/1 model structure shown in Equation 2.1 was used to estimate the delay, meaning that vehicles entering the ramp are assumed to follow a Poisson distribution, and the exit pattern is deterministic, one vehicle at a time. During the process of determining which ramps were metered, a location in the network with a missing ramp was discovered. A link representing the ramp from southbound I-35W to westbound I-94 was added at this time.

$$\bar{W} = \frac{\rho}{2\mu(1-\rho)} \tag{2.1}$$

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 1997, 2000 and 2005. Data from 1997 was used to approximate conditions in 1995 because the amount of detector data available in 1997 is much greater. The service rates were taken from Mn/DOT target values used when queue detection is unavailable. Some ramps that are no longer metered but were metered in some or all of the analysis years were not included in the target rate file. For these ramps, the maximum provided rate of 1714 vehicles per hour was used. The underlying assumption is that the meters would have been turned off in locations where congestion is either very low and traffic is not delayed, or congestion is high enough that the meters would have been operating at their maximum rate.

Equation 2.1 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 rests on the assumption that there is no standing queue at the beginning of the peak period, and that by the end of the peak period, demand has slowed such that service can catch up. The peak periods chosen were 7:30-8:30 A.M. and 4:30-5:30 PM, in order to be consistent with the periods used for the freeway travel times. The peak period 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 2.1 would result in negative delay. In these cases, the service rate was increased to at least the arrival rate plus 10 percent.

Average delay estimates resulting from the calculations are shown in Figures 2.1-2.6. The M/D/1 model resulted in lower average peak-period delays than expected. To corroborate the results, queue detector occupancy data were collected for five ramps with high peak volumes. This information is displayed in Figures 2.7-2.16 as histograms of the average occupancy during each five-minute increment of the peak period. In this case, the peak periods are defined as 6:00-9:00 A.M. and 3:00-6:00 PM, and the data represent each Wednesday in 2005. The longer time frames were used to ensure the times of peak occupancy were reflected in the figures, even if they fall outside the peak hour used for the rest of the analysis. The figures show that even for the busiest ramps, very high queue detector occupancy is observed for only a few periods each year.

[1] Email correspondence with Brian Kary and Jesse Larson at Mn/DOT provided helpful data and explanation.

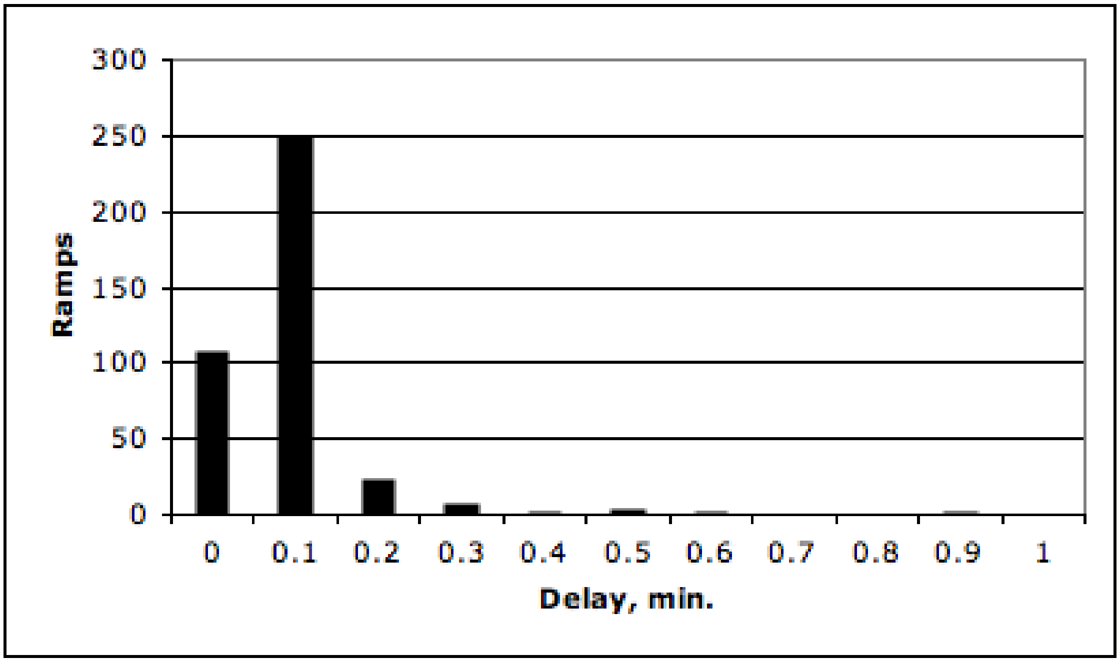


Figure 2.1: 1997 Average A.M. peak-period delay for all ramps.

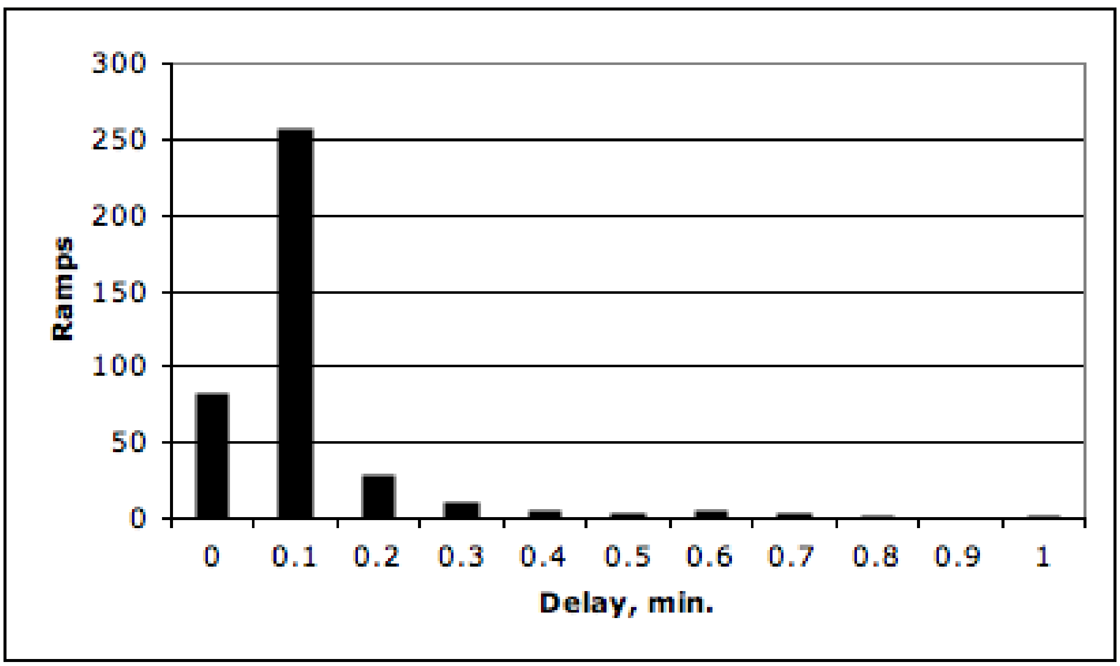


Figure 2.2: 1997 Average P.M. peak-period delay for all ramps.

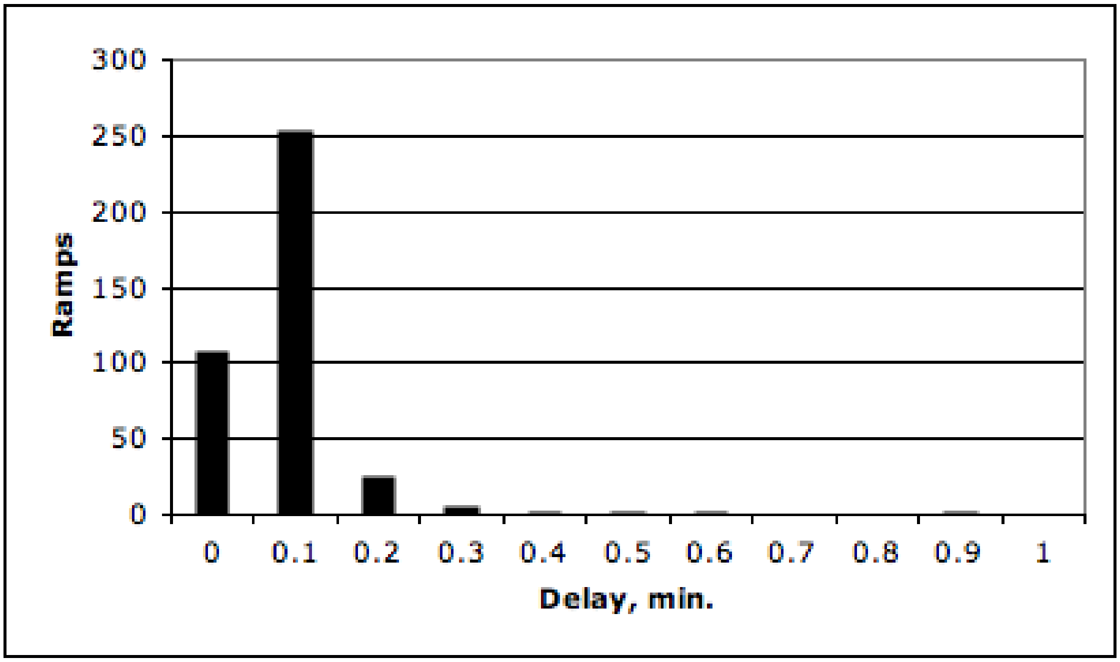


Figure 2.3: 2000 Average A.M. peak-period delay for all ramps.

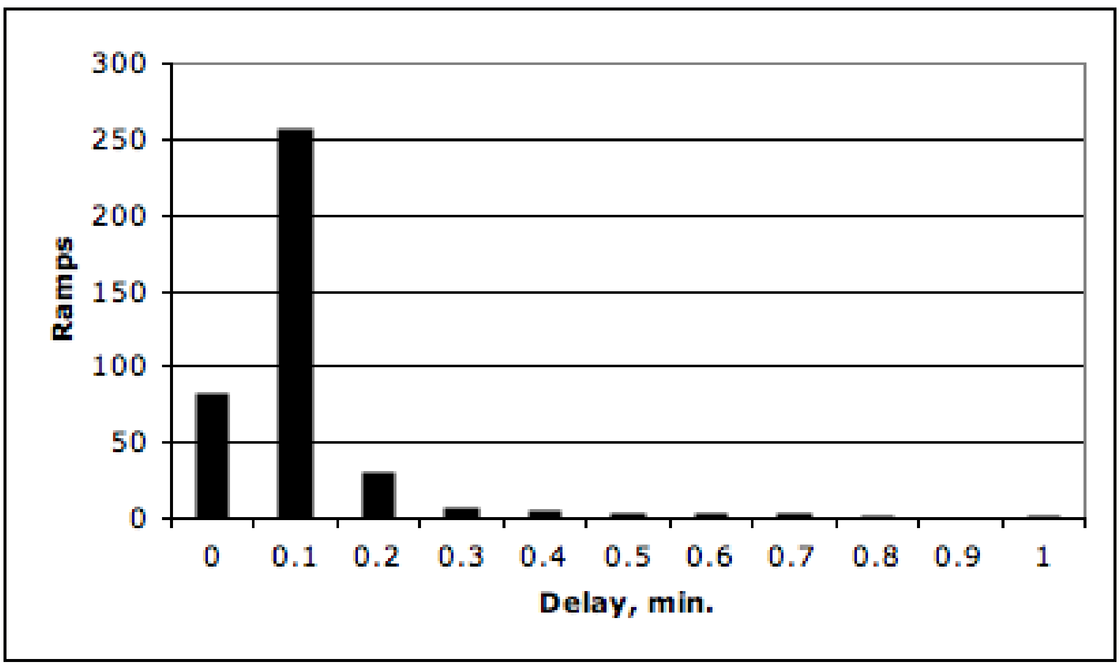


Figure 2.4: 2000 Average P.M. peak-period delay for all ramps.

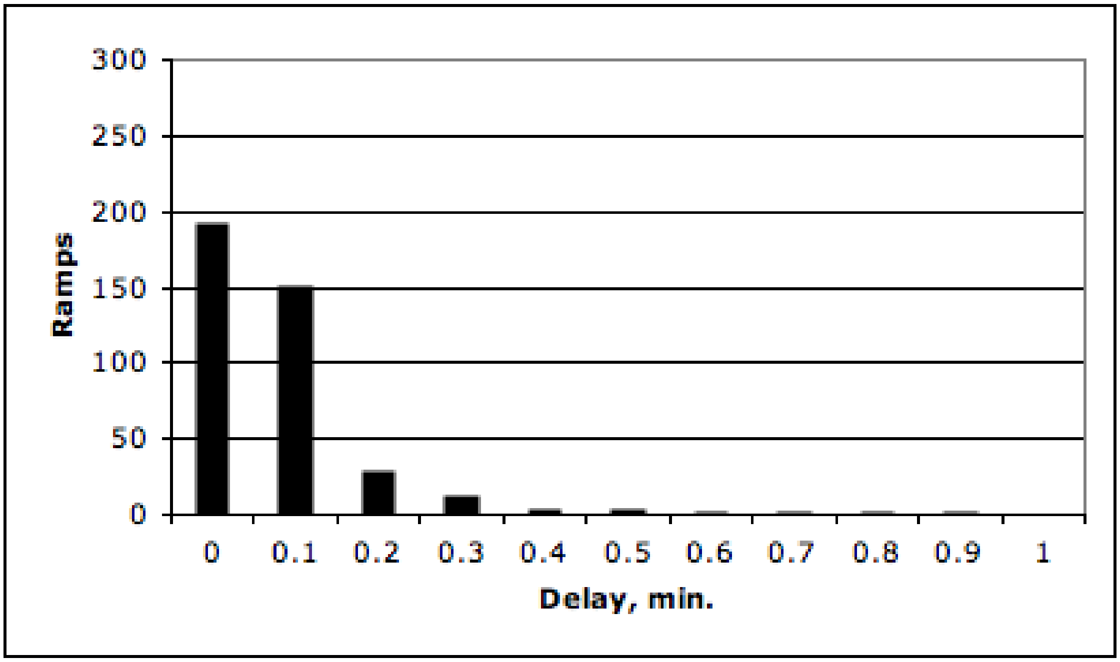


Figure 2.5: 2005 Average A.M. peak-period delay for all ramps.

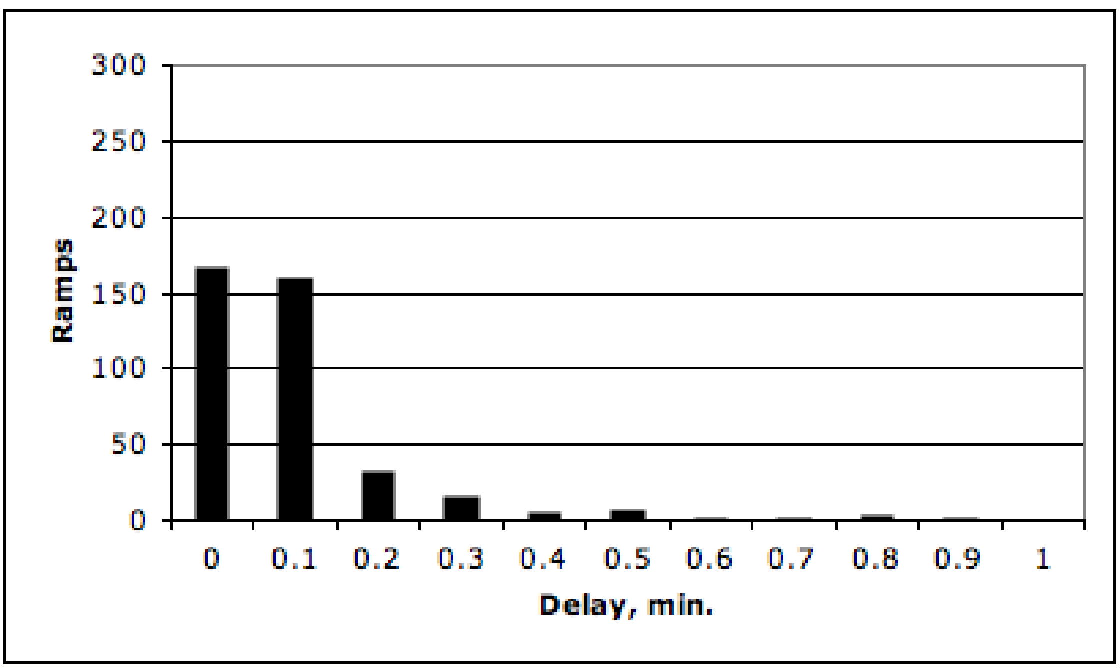


Figure 2.6: 2005 Average P.M. peak-period delay for all ramps.

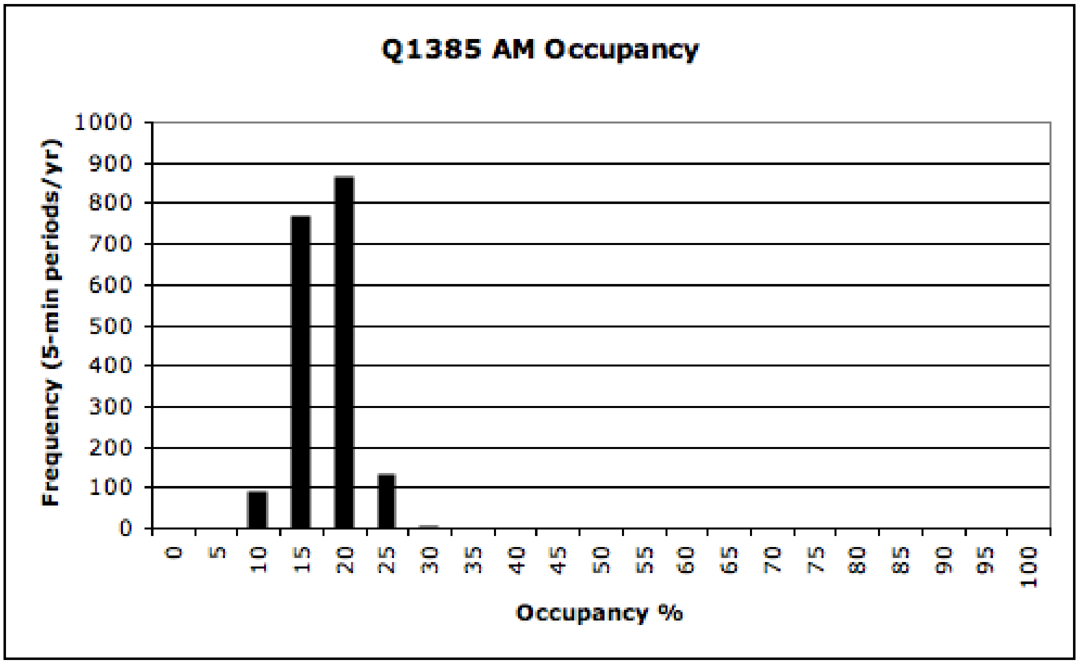


Figure 2.7: Morning peak-period queue detector occupancy at Broadway to I-94 SB.

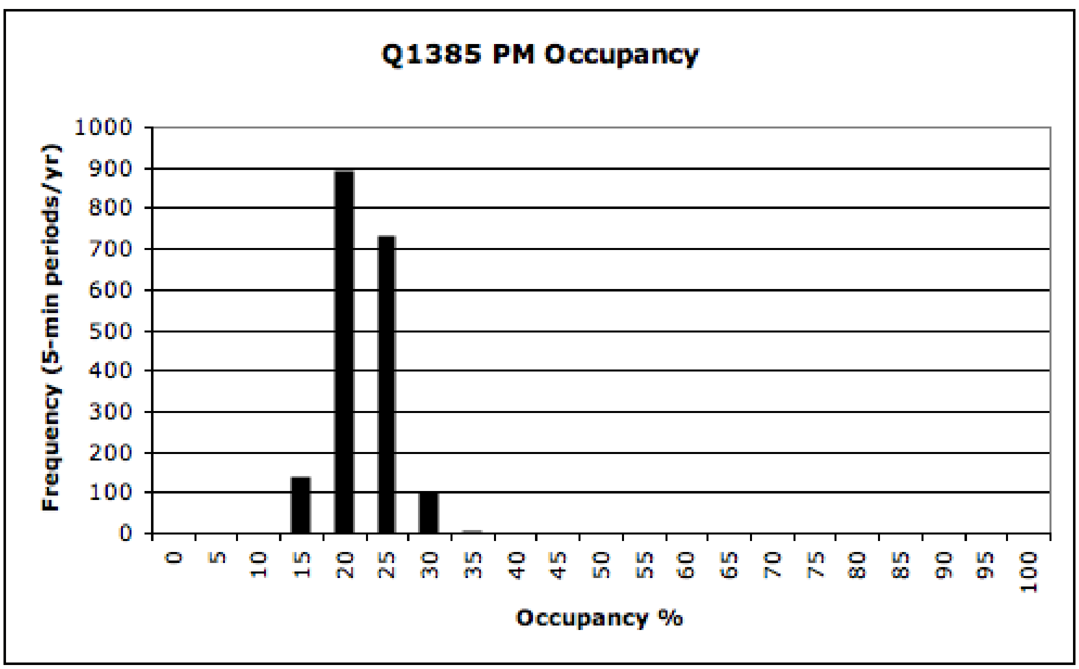


Figure 2.8: Evening peak-period queue detector occupancy at Broadway to I-94 SB.

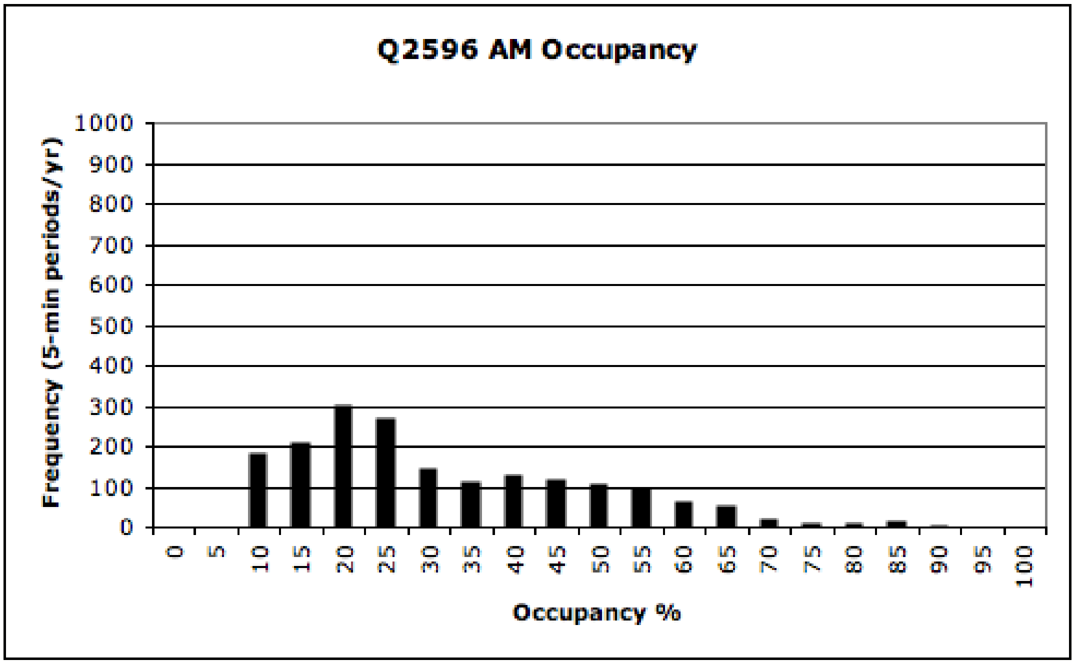


Figure 2.9: Morning peak-period queue detector occupancy at Snelling to I-94 WB.

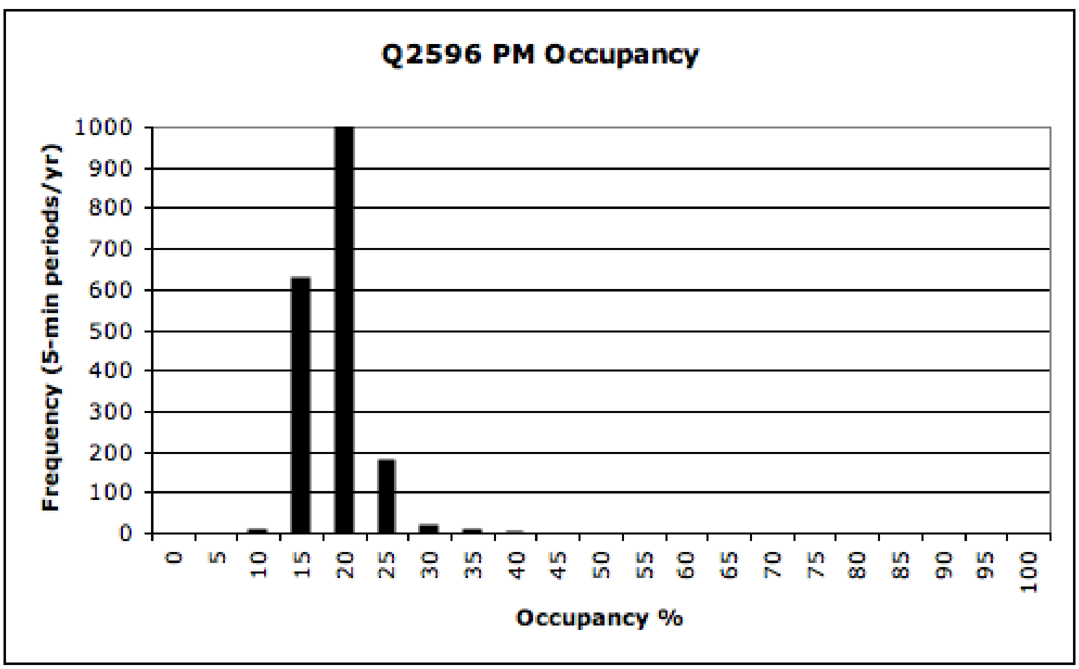


Figure 2.10: Evening peak-period queue detector occupancy at Snelling to I-94 WB.

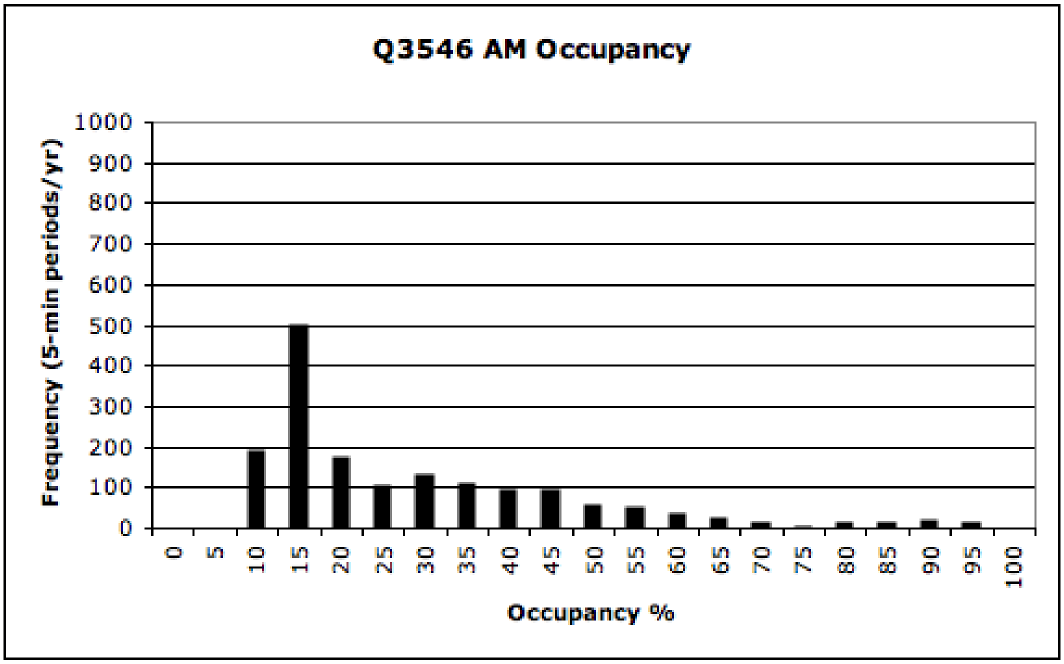


Figure 2.11: Morning peak-period queue detector occupancy at 169 SB to I-394 EB.

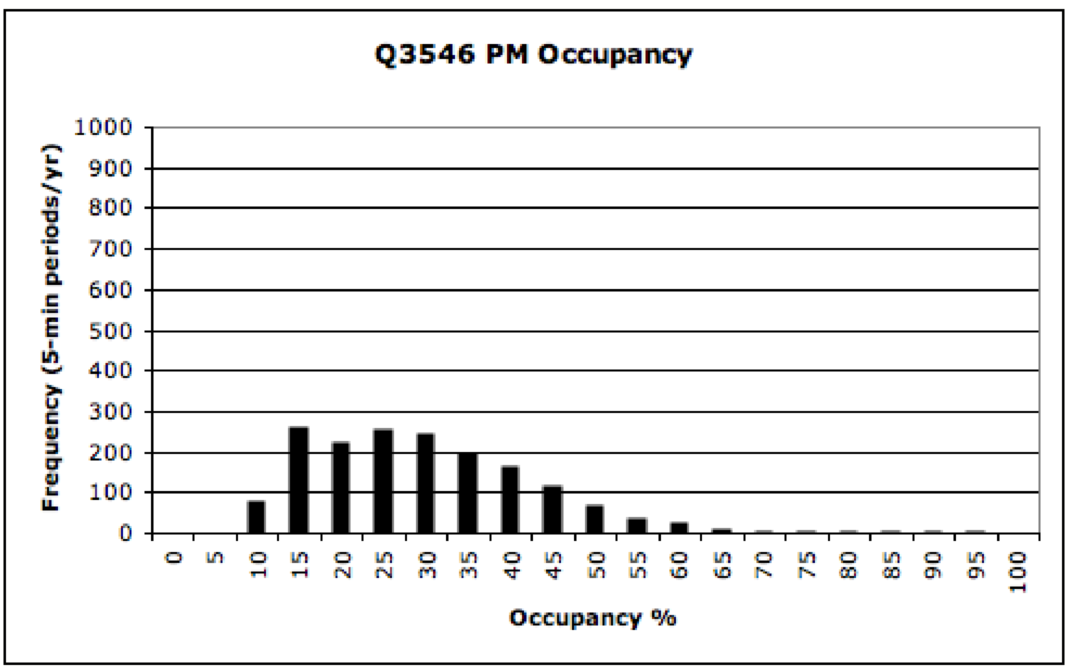


Figure 2.12: Evening peak-period queue detector occupancy at 169 SB to I-394 EB.

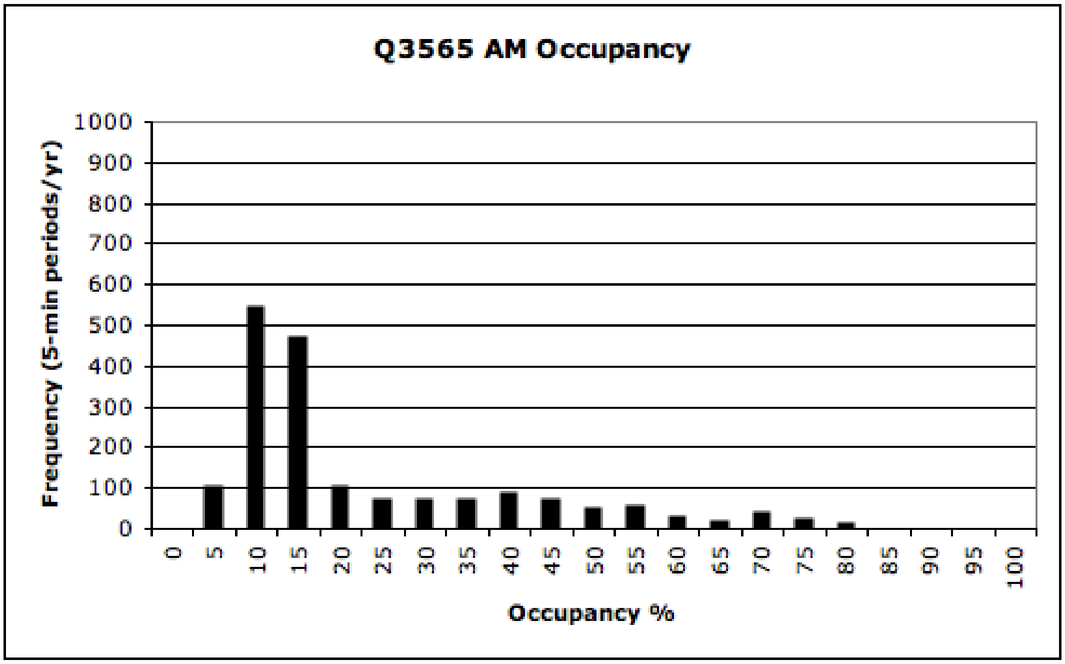


Figure 2.13: Morning peak-period queue detector occupancy at 100 NB to I-394 EB.

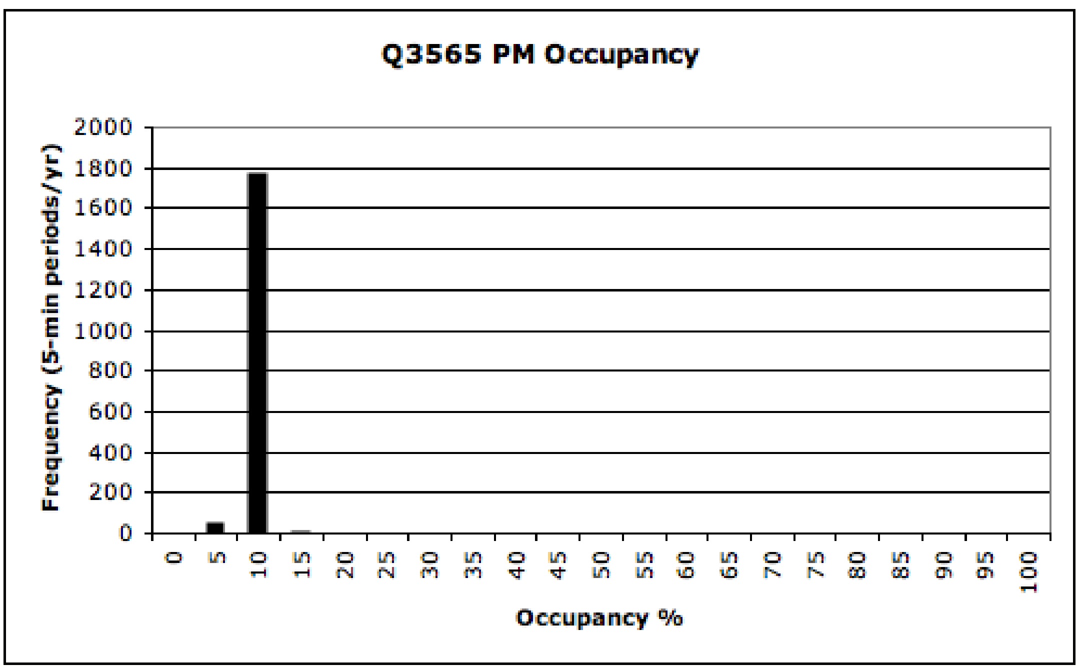


Figure 2.14: Evening peak-period queue detector occupancy at 100 NB to I-394 EB.

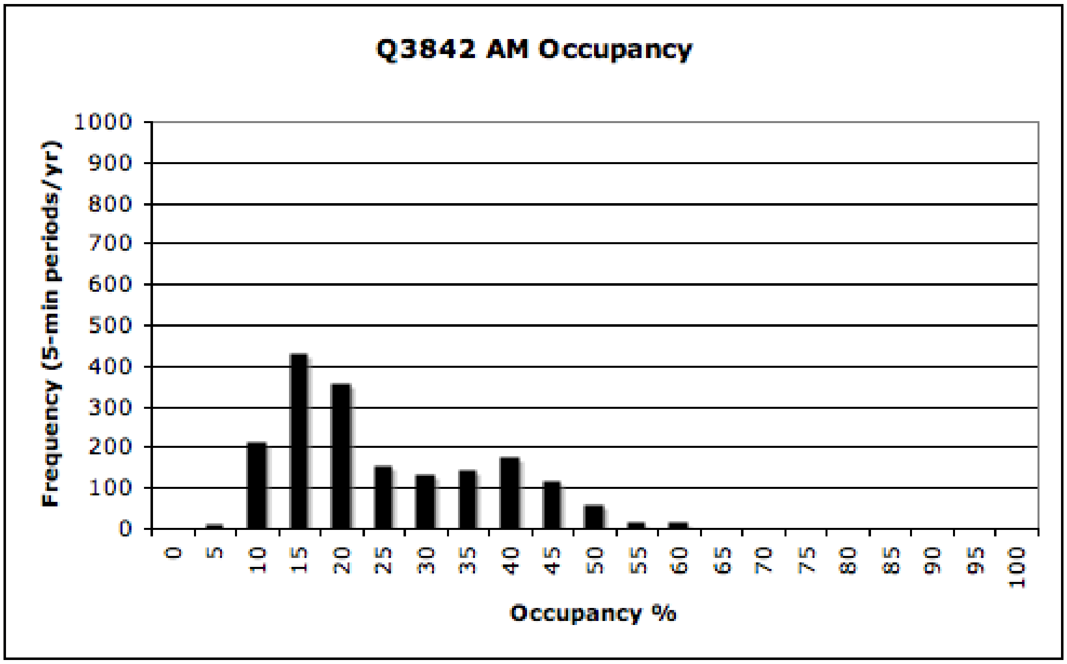


Figure 2.15: Morning peak-period queue detector occupancy at I-694 EB to I-35W SB.

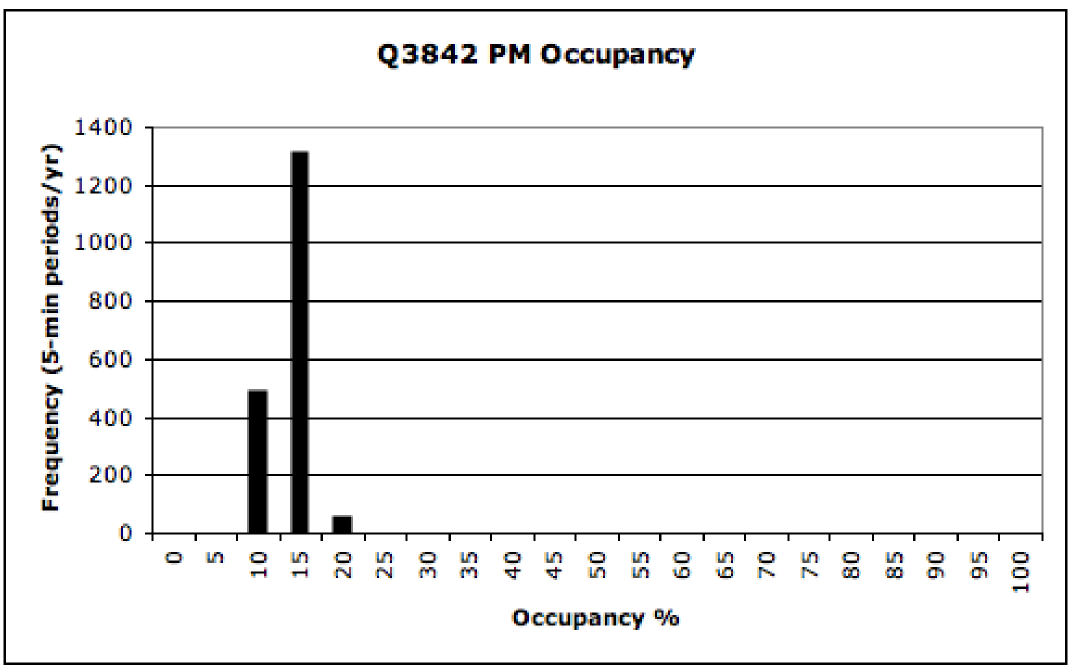


Figure 2.16: Evening peak-period queue detector occupancy at I-694 EB to I-35W SB.

2.5 Arterial Travel Time Estimation

The estimation of travel times on arterial links presents a particularly complex task. Not only is the network from which link travel times are extracted expanded to include many collector streets in addition to the standard network of arterials provided in the region's transportation planning model, but additional emphasis was placed on finding a method that improved accuracy by allowing for the use of intersection signal control information. The first phase of research into the estimation of arterial travel times, described by Davis and Xiong [2], focused on identifying and then evaluating a set of parametric models for producing default estimates of travel times on arterial links. Several candidate travel time models were evaluated, including the Bureau of Public Roads (BPR) link performance function, the Conical Volume-Delay function, the "Singapore" model, the Skabardonis-Dowling model, and the Highway Capacity Manual (HCM) formula, based on the 2000 edition of the Transportation Research Board's *Highway Capacity Manual*.

The five methods were compared by applying them to a set of 50 sample arterial links located throughout the region using a license plate matching method. They were also tested using varying degrees of site-specific information (e.g., free-flow speed, lane capacity) to determine the sensitivity of the travel time predictions of each model to the level of site-specific information provided. The results of the evaluation of the five arterial travel time models indicated that the Skabardonis-Dowling model would be the best candidate for further study, based on its performance in terms of prediction accuracy and its ability to incorporate signal timing information in its prediction of link travel time. Mathematically, the Skabardonis-Dowling model is defined as:

$$TT = \left(\frac{L}{FFS} + 0.5NC\left(1-\frac{g}{C}\right)^2 PF\right)\left(1+0.05\left(\frac{v}{c}\right)^{10}\right) \tag{2.2}$$

where:

TT = predicted mean travel time
FFS = free-flow travel speed
N = number of signals in the link
C = cycle length
g = effective green time
PF = progression adjustment factor
v = volume, and
c = capacity (adjusted by green time/cycle length ratio)

The progression adjustment factor (PF) is given by:

$$PF = \frac{(1-P)f_{PA}}{1-\frac{g}{C}} \tag{2.3}$$

where:

P = proportion of vehicles arriving of green
$\frac{g}{C}$ = proportion of green time available, and
f_{PA} = supplemental adjustment factor for platoon arriving during green (approximately equal to 1)

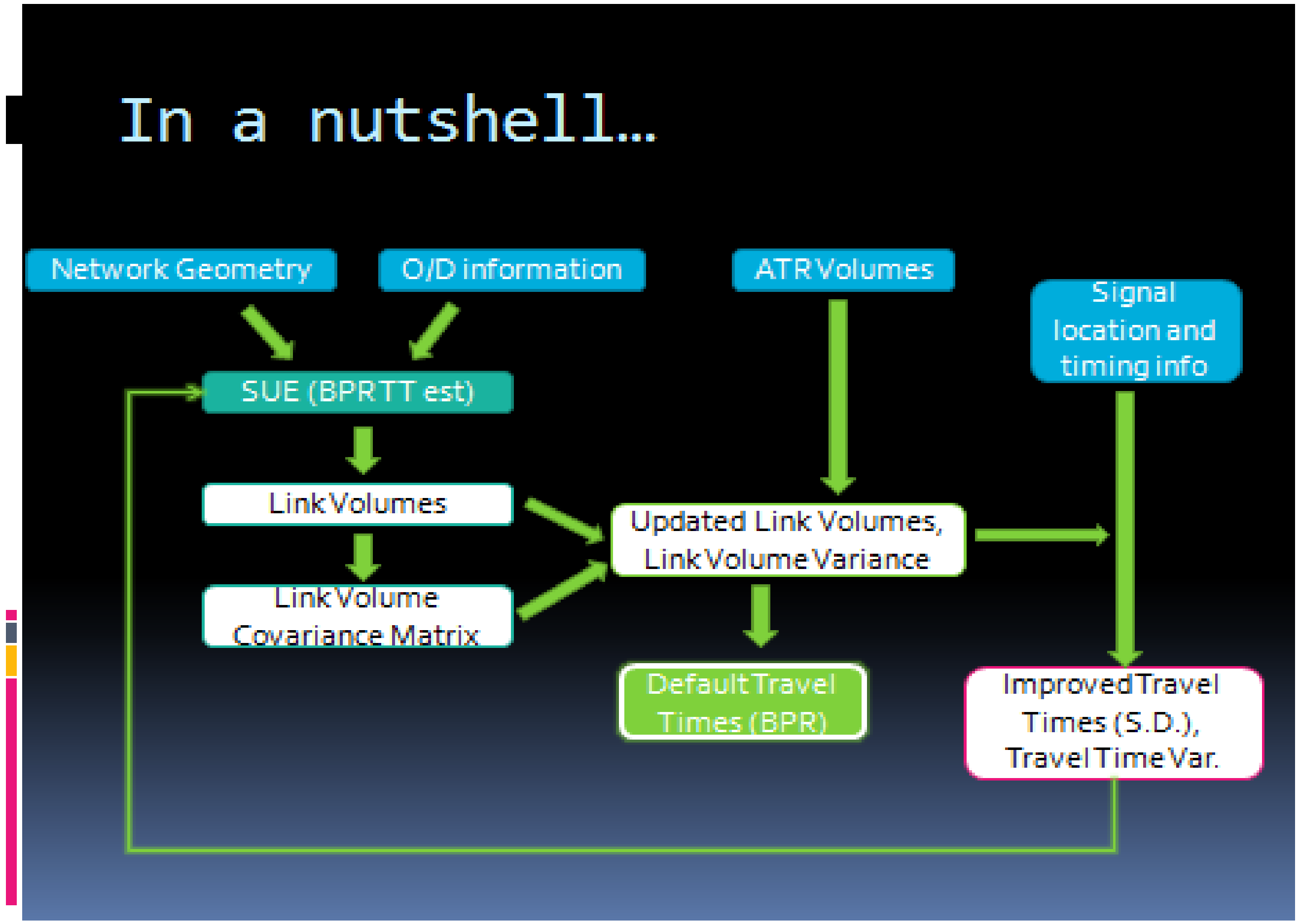
Based on the findings of the evaluation of the candidate arterial link travel time estimation models, the second phase of research into arterial travel time estimation sought to produce network-wide estimates of arterial travel times for the target years of the study. Using estimated network-wide link volumes and the signal timing information embodied in the Skabardonis-Dowling model, it becomes possible to produce improved estimates of arterial travel times link by link.

The process of obtaining the estimates of the arterial link travel times is described in Figure 2.17. Initial link volume flows are obtained by performing a stochastic user equilibrium (SUE) assignment on the arterial links using a transportation planning model with default parameters. The demand inputs are taken from origin-destination (O-D) tables maintained by the Metropolitan Council for use in planning models. Separate O-D tables were used for each time of day, and this is responsible for some of the variation in travel speed on the same links between the morning and the afternoon. The speeds resulting from the SUE process are more reliable for lower-volume routes on which peaking has less effect and there is less variation over the course of the day.

The volumes produced by the SUE assignment can be validated against traffic counts provided by automatic traffic recorder (ATR) stations located along some arterial links. For links where no ATR count data are available, link volumes can be updated by making assumptions about the distribution of link flows and utilizing information about the estimated means and variances of flows on links for which ATR counts are available. The resulting set of link volumes and link volume variances can be used as inputs to an arterial travel time estimation model. In the absence of complete signal timing information, default travel times can be obtained from a simpler travel time estimation model, such as the BPR link performance function. If full signal timing and location information can be obtained, then improved travel times and variance estimates will be produced using the Skabardonis-Dowling model. As Figure 1 indicates, these travel time estimates can be fed back into the SUE assignment model and used to produce link flow estimates for the following time period.

To connect the TAZ centroids to the network, dummy links were created. The time assigned to these links represents the intrazonal travel time needed to reach the nearest collector or arterial. Since much of this travel is assumed to take place on local streets, these links were assigned speeds of 23 miles per hour. These links serve only to provide network access for the zones, and cannot be used by traffic traveling between two other zones.

Figure 2.17: Process of generating arterial link volumes and travel times.



2.6 Matrix Estimation

After average travel times were associated with each link in the network, a shortest-path algorithm was used to determine network travel times between each TAZ centroid and all others. The assumption behind this algorithm is that travelers will always try to minimize travel time between their origins and destinations. This is not necessarily the case, because some travelers might value shortest-distance routes even if travel times are slightly longer. Also, in reality the process is iterative, and link speeds can change as volume changes. In this model, the observed speeds are assumed to hold. The routes between each origin and destination with the shortest travel times were calculated in TransCAD 4.8, which uses a version of Dijkstra's algorithm. Separate travel time matrices were constructed for each analysis year. The intrazonal travel times were calculated as half the average travel time to the nearest three adjacent zone centroids.

2.7 Conclusion

This section has described the process of generating the components of a zone-to-zone travel time matrix to be used as an input to the development of regional accessibility measures. The major components of the travel time matrix are freeway travel time estimates, estimates of freeway ramp delay, and arterial travel time estimates. It appears that in most cases it will be possible to obtain link travel time estimates based observed traffic volumes for each of the target years in the study. Where data or other important pieces of information are missing (e.g., collector volume counts, signal timing information), imputation and updating methods may be employed to produce estimates of the missing values. The result is an improved, robust and more detailed matrix of network travel times that provide a best estimate of the time cost of interaction between a multitude of origins and destinations in the Twin Cities region.

Chapter 3

Methodology

Taken by itself, the travel time matrix generated above measures *mobility*. The information it contains is enough to determine the speed at which network users can travel from any analysis zone to any other. However, transportation is often described as a derived demand, which means that mobility is not an end in itself, but is necessary due to the spatial separation of other activities or objectives [7]. As long as travel is occurring for reasons other than pleasure, the proximity of demanded destinations must be considered along with mobility in order to evaluate the benefits of network performance to the user. In short, the possibility of high-speed travel is of limited use if the distance between origins and destinations is great. Weighting *mobility* by the number of opportunities it presents to arrive at *accessibility* can help direct investment in network improvements not merely toward where speed will be increased the most, but to where the increased speed will provide the greatest improvement in terms of access to desired destinations. Where mobility improvements respond to a derived demand, increased accessibility addresses a more basic need.

Accessibility can be thought of as the potential opportunity for interaction [3]. In this analysis, cumulative opportunity measures are calculated as total numbers of jobs, residents and workers reachable from each point in a given time period. This measure was chosen because it is spatially continuous and suitable for creating maps to compare changes in accessibility across the region. Maps showing extents of equal accessibility can also be created, similar to topographic contour maps showing lines of equal elevation. Alternative measures could be either gravity- or utility-based. Gravity measures introduce an additional complication in that an appropriate function of distance must be chosen. Utility is a difficult concept to quantify, because individual residents place widely varying value on access to different things.

The Hansen accessibility measure is traditionally defined as:

$$A_i = \sum_{j=1}^{n} O_j f(C_{ij})$$

where:

A_i = accessibility from a zone (i) to the considered type of opportunities (j)
O_j = opportunities of the considered type in zone j (e.g., employment, shopping, etc.)
C_{ij} = generalized (or real) time or cost from i to j

$f(C_{ij})$ = Impedance function (exponential or power functions are most often used)

Here we use a cumulative opportunities function, which defines $f(C_{ij}) = 1$ if $C_{ij} < T$ and 0 otherwise. The threshold T, indicating the time for which we will compute the number of activities that can be reached, varies from 5 minutes to 60 minutes depending on the map, allowing us to examine both long and short trips. The cumulative opportunities function satisfies five criteria [4]: Cumulative, Comparable, Clear, Comprehensive, and Calculable, some of which escape other more complicated measures.

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

$$A = \frac{\sum_{i=1}^{n} A_i W_i}{\sum_{i=1}^{n} W_i}$$

Chapter 4

Results

4.1 Accessibility to Jobs and Workers

The changes in accessibility from 1995 to 2005 are described in this section. The most striking trend one notices is that in fact, accessibility by automobile increases almost everywhere over this period for the larger timebands. The change in land use and densification of activities outweighs any increase in congestion in this period. While in 1995 only one traffic analysis zone could reach more than one million jobs within 20 minutes, by 2005 that number had increased to 20. Within 30 minutes, well more than half the population of the region can reach over one million jobs, while within 45 minutes, almost everyone in the Twin Cities region can reach more than one million jobs by auto. All of this is not to say there were no accessibility losses, as there were some, but they were outweighed by gains.

When the travel times are low, accessibility is concentrated in the urban centers of Minneapolis and St. Paul. As the allowed travel times increase, corridors of relatively high accessibility become evident along major highways, especially I-35W south of downtown Minneapolis. Downtown St. Paul diminishes in accessibility compared to other points in the region once the radius is increased to a 25-minute travel time. Although it is a dense cluster of opportunities within a five-to-ten-minute trip, it is relatively isolated from other development density centers such as the I-494 corridor in the south-southwest part of the region. When opportunities within a 30-minute reach are considered, the concentrations along highway routes are no longer obvious, and the gaps between major routes begin to fill in. From 35 to 60 minutes, accessibility gains radiate outward from a point in the center of the region closer to downtown Minneapolis than downtown St. Paul.

In general, the southern portion of the region has access to more destinations in shorter travel times than the north. Once 40 minutes are allowed for travel, residents of all but the most rural zones have access to at least 100,000 jobs. The least accessible zones are in the southwest corner of the region, but this should be qualified by noting that more jobs in locations outside the seven counties may be reachable from these zones. Other points of interest due to their effects on accessibility are areas that may be near or adjacent to the mainlines of high-speed routes but some distance away from the nearest onramp. An example of this is the area south of Highway 62 between I-35W and Highway 77. Another factor that affects accessibility adversely that can be seen in the maps appears in places with large gaps between river crossings.

Access to jobs is flatter across the region in the P.M. peak period than the AM, meaning the difference between the points with high and low accessibility is not as great. Access to workers is not noticeably flatter, but is lower.

Also of note is that the accessibility gains at the edge of region outweigh those in the center. The suburbs are more accessible in 2005 than they were in 1995, while changes in the already highly accessible center city have been much more modest. Overall person-weighted accessibility by county is given in Figure 4.1,

The detailed results are illustrated in Figures 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13 for job accessibility by auto by 5 minute timeband for 1995 and 2005 for the A.M. peak period.

Similar results are seen in Figures 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, 4.25 for accessibility to workers by auto by 5 minute timeband for 1995 and 2005 for the A.M. peak period.

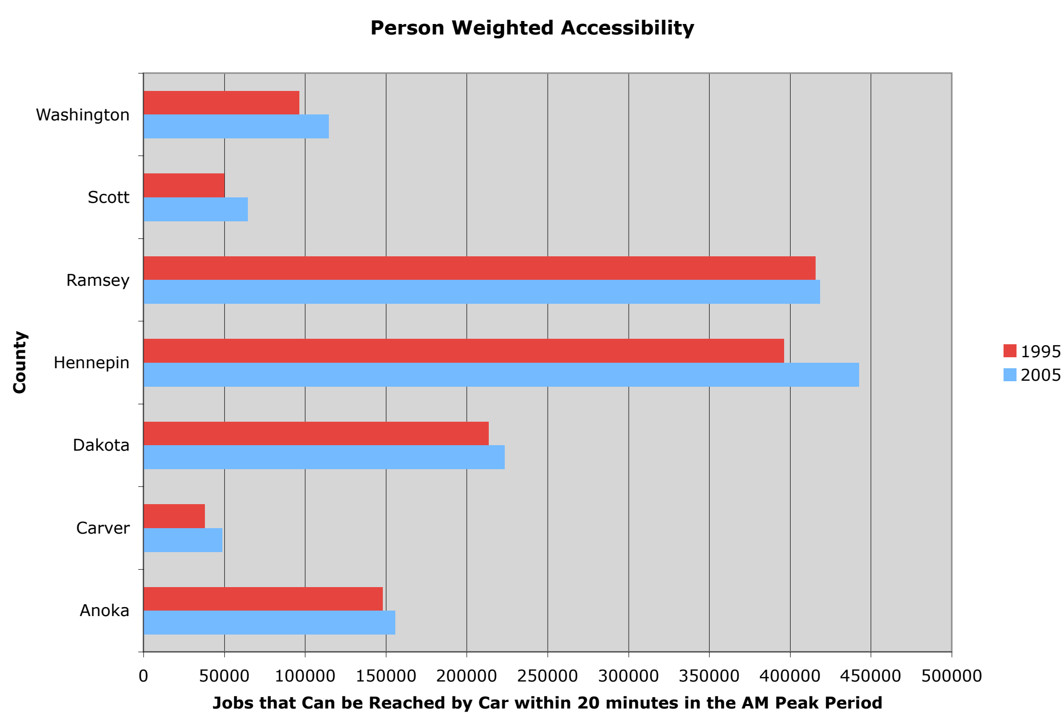


Figure 4.1: Person-weighted accessibility to jobs by county.

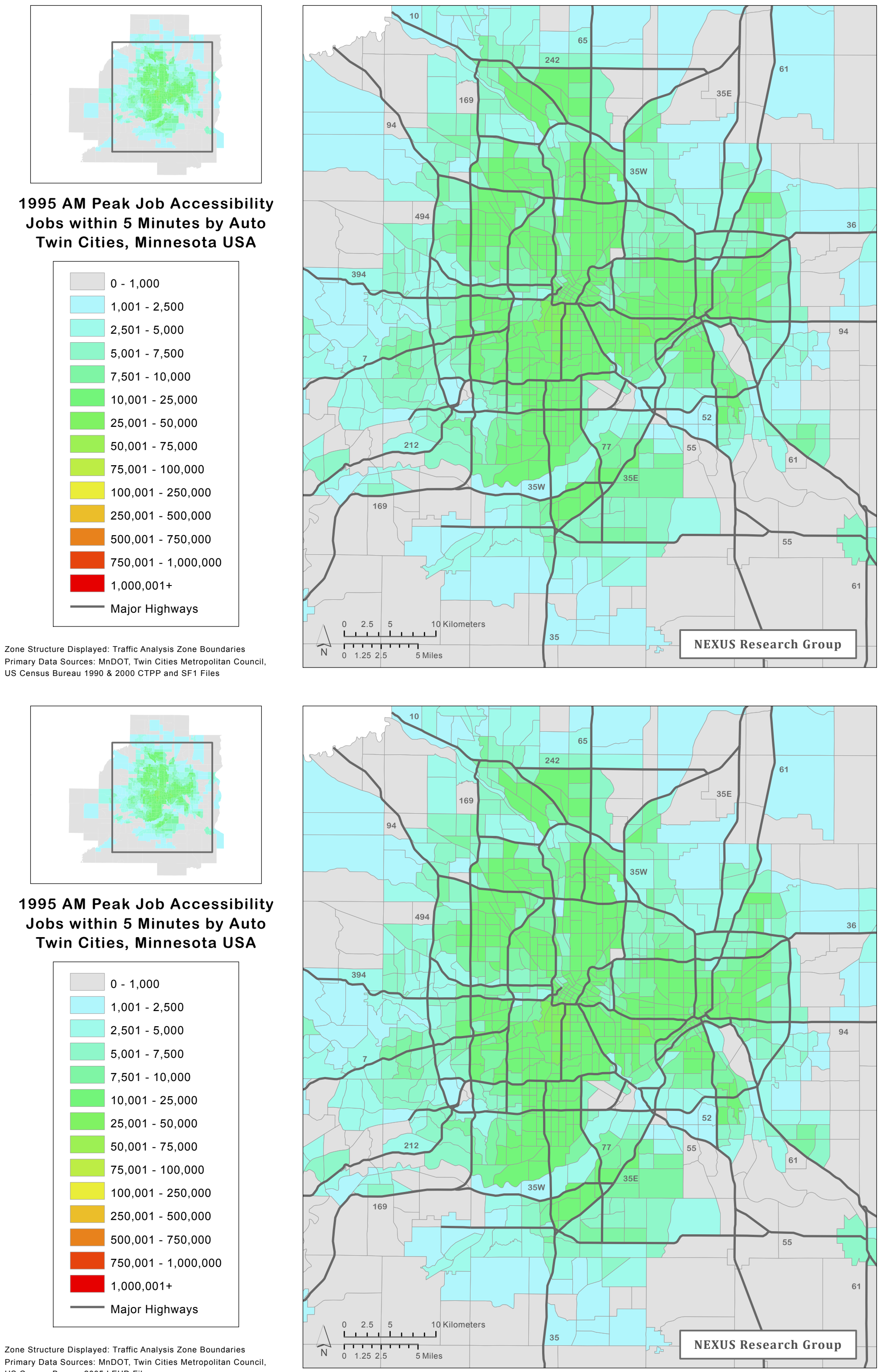


Figure 4.2: Jobs accessible within 5 minutes.

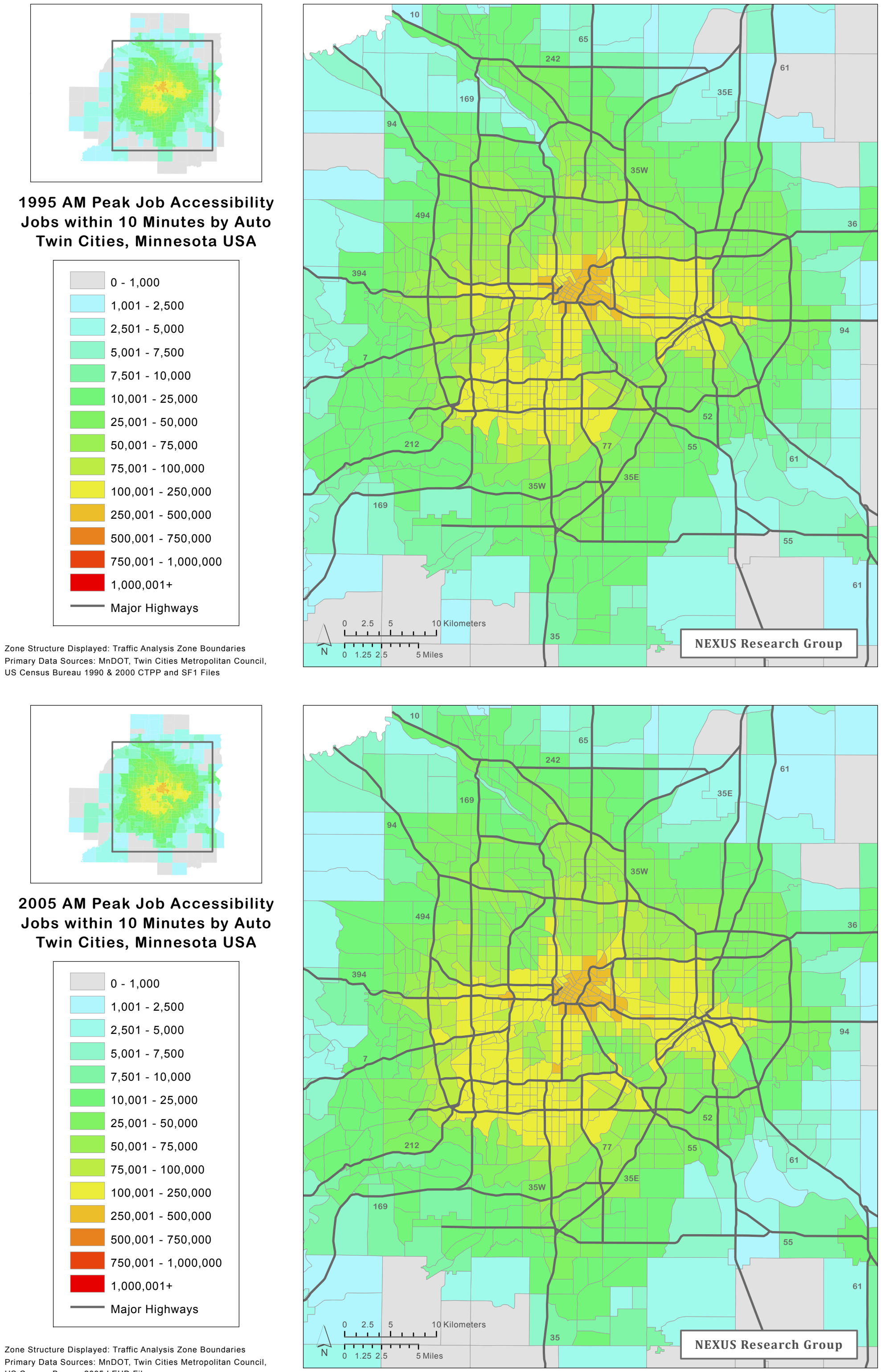


Figure 4.3: Jobs accessible within 10 minutes.

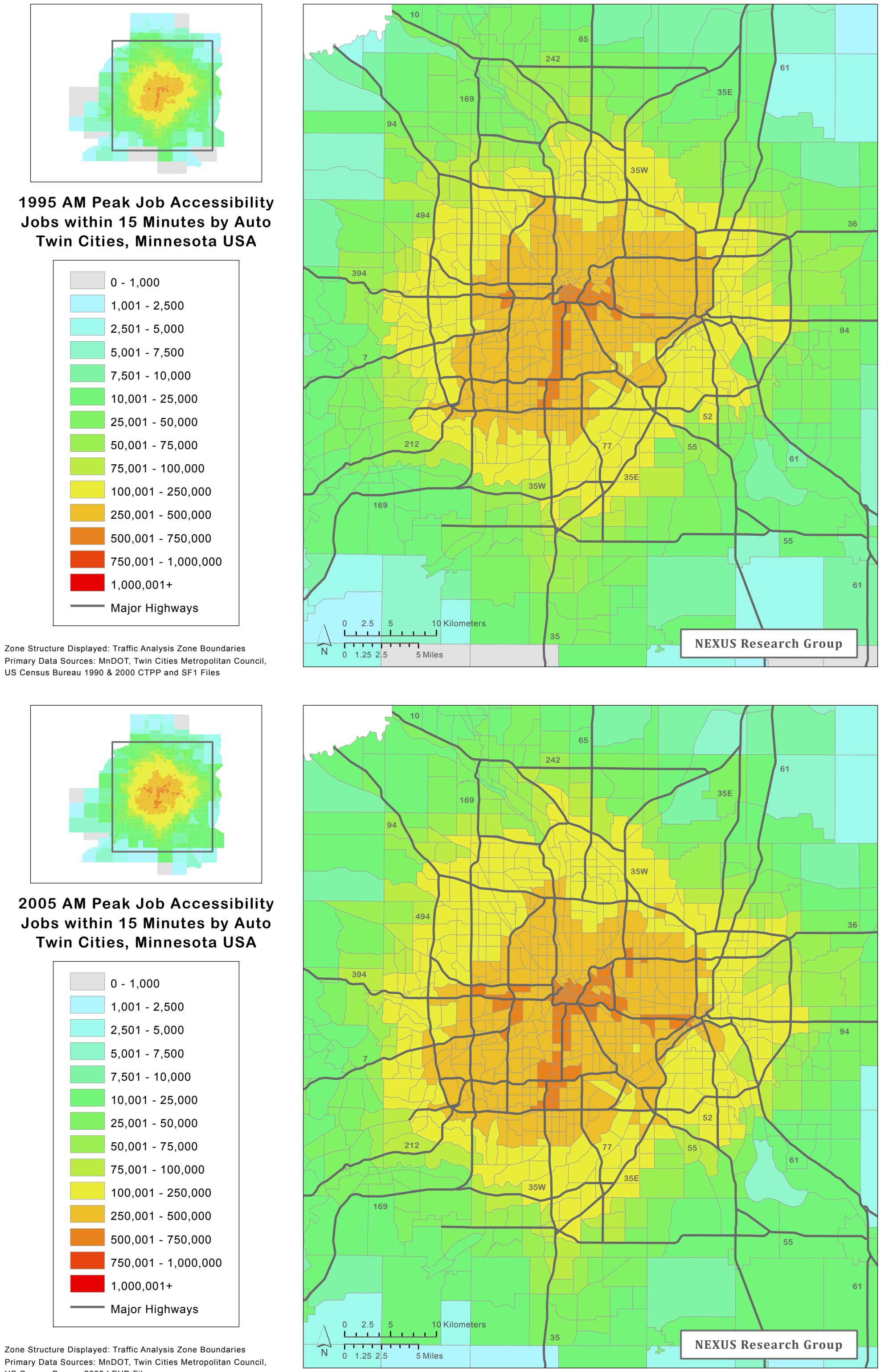


Figure 4.4: Jobs accessible within 15 minutes.

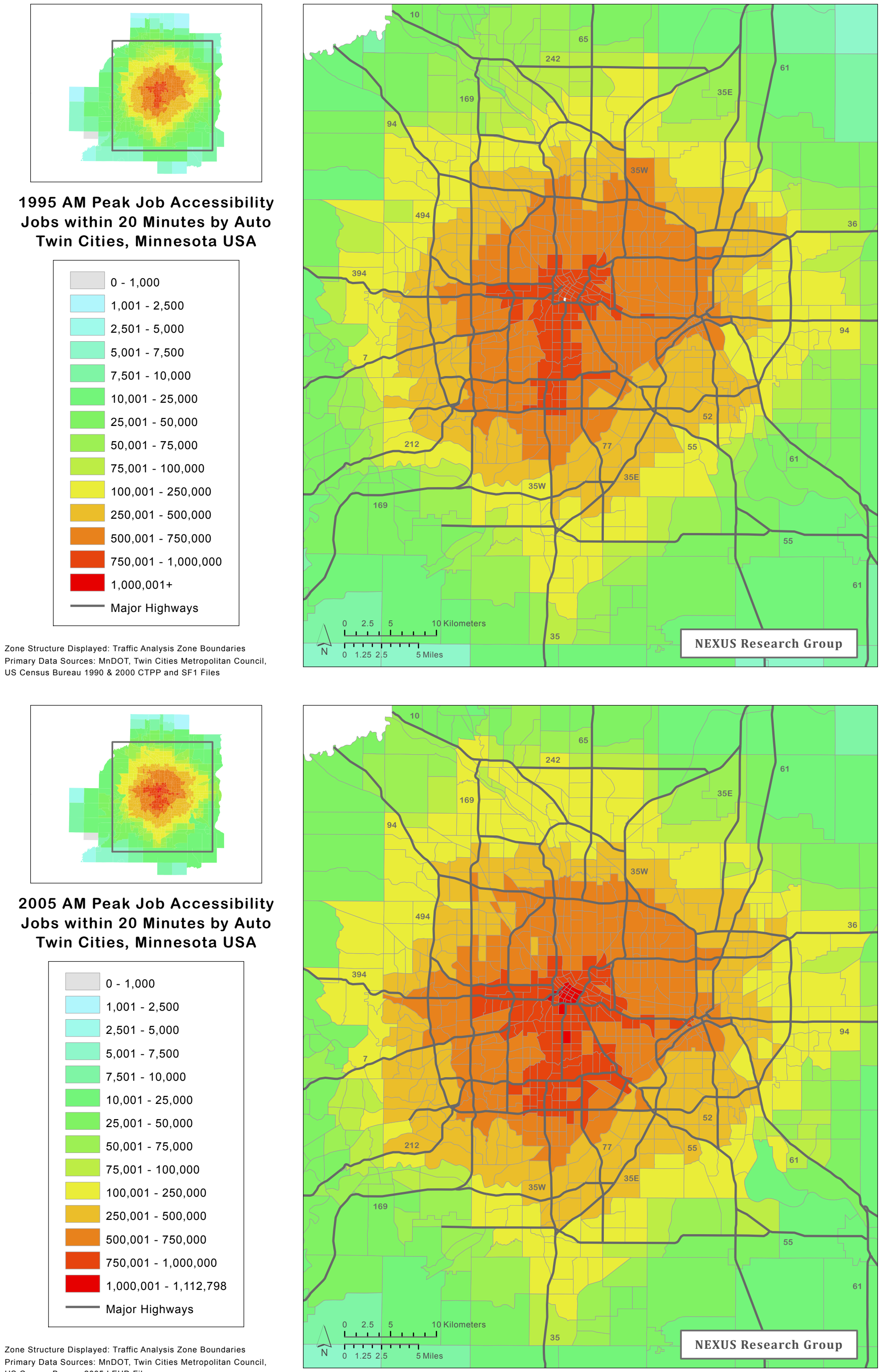


Figure 4.5: Jobs accessible within 20 minutes.

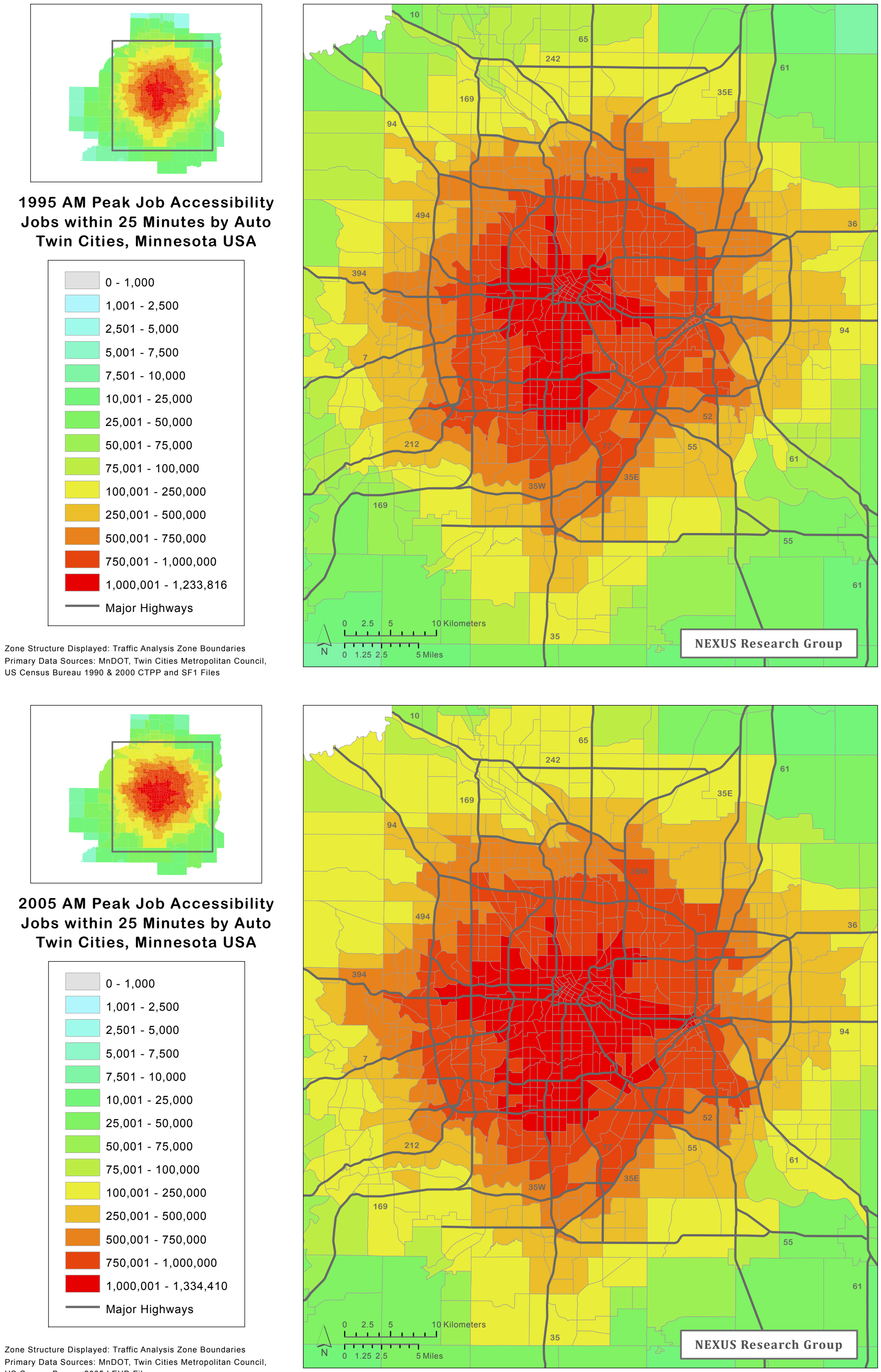


Figure 4.6: Jobs accessible within 25 minutes.

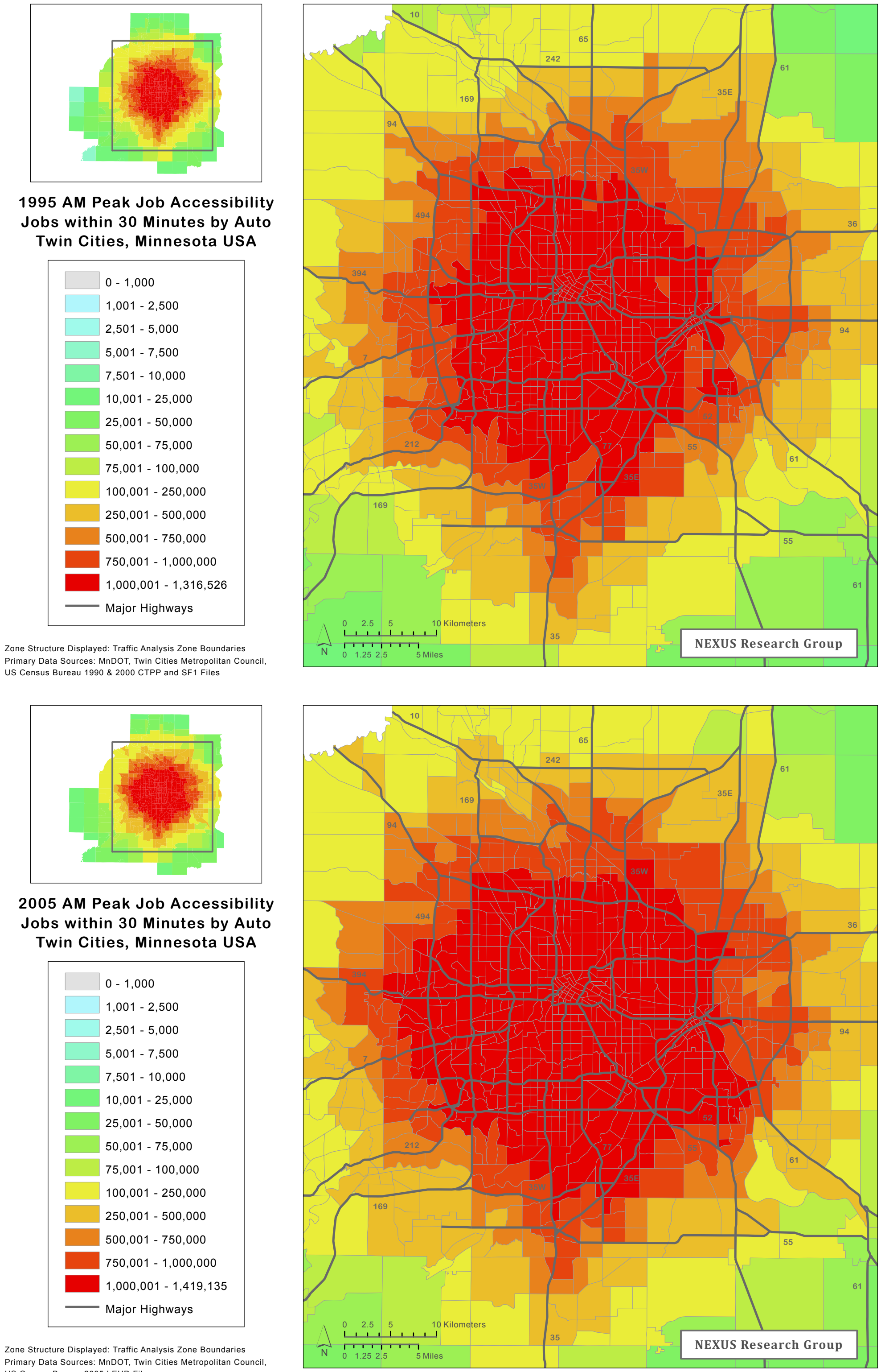


Figure 4.7: Jobs accessible within 30 minutes.

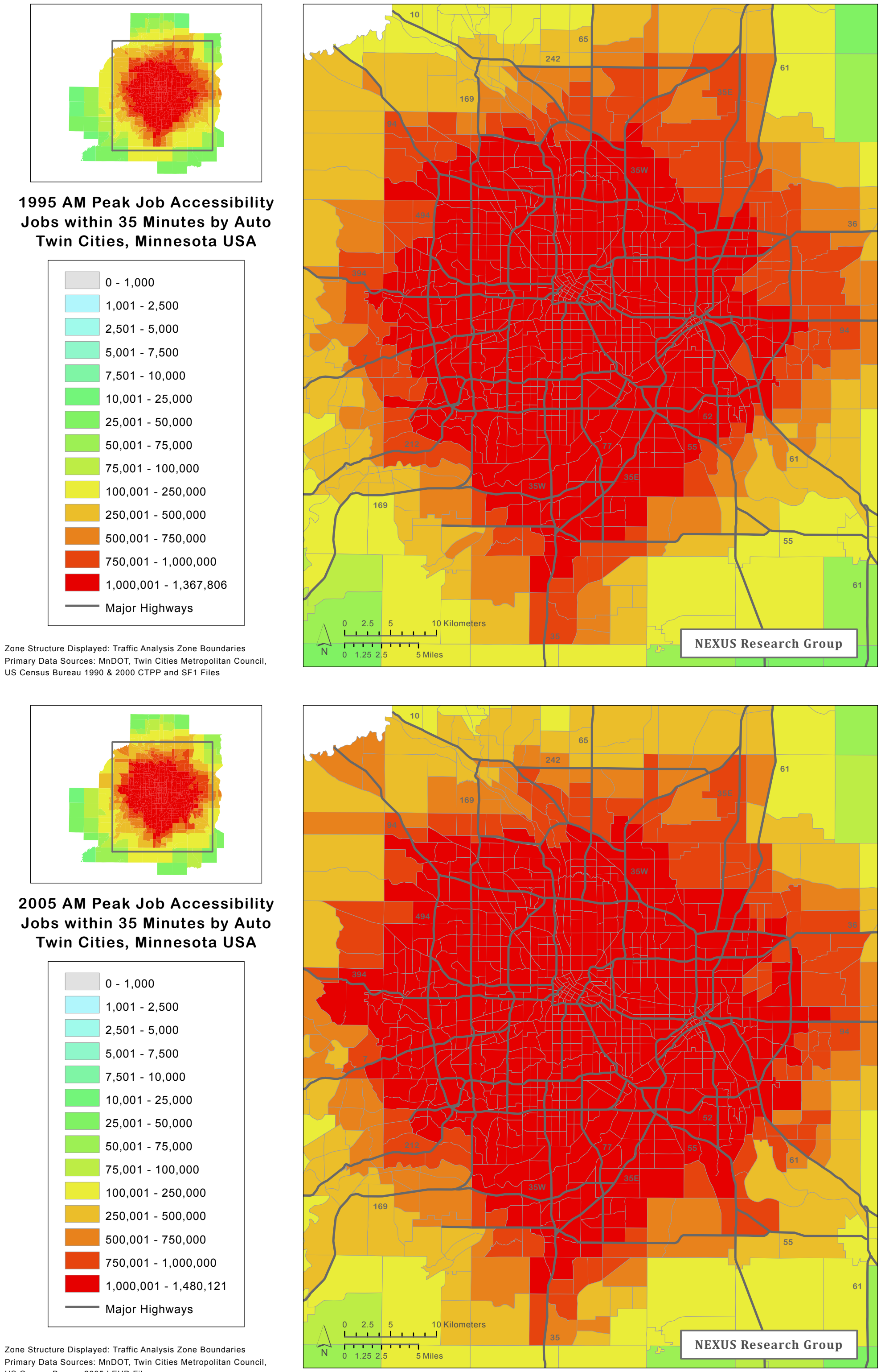


Figure 4.8: Jobs accessible within 35 minutes.

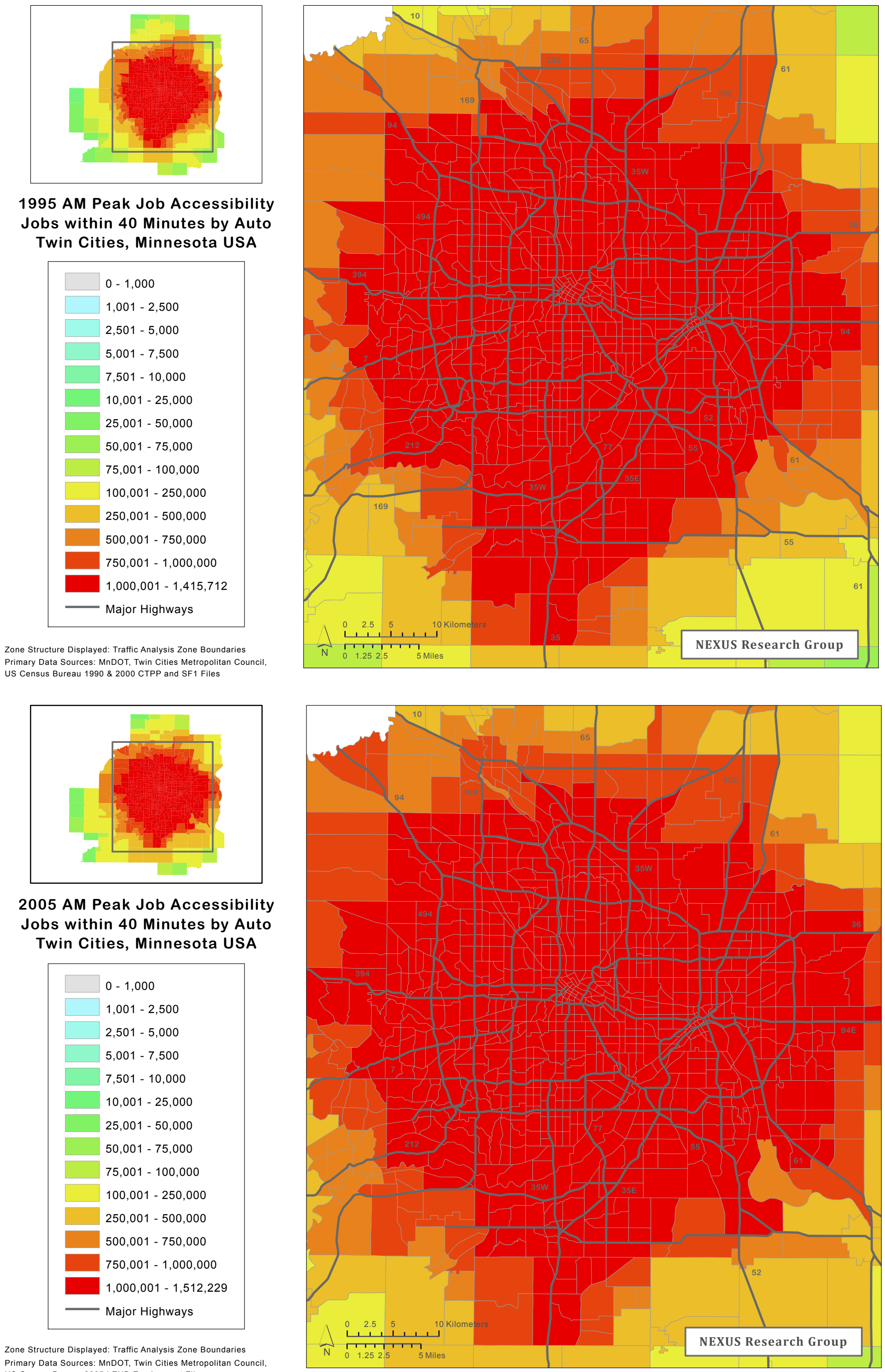


Figure 4.9: Jobs accessible within 40 minutes.

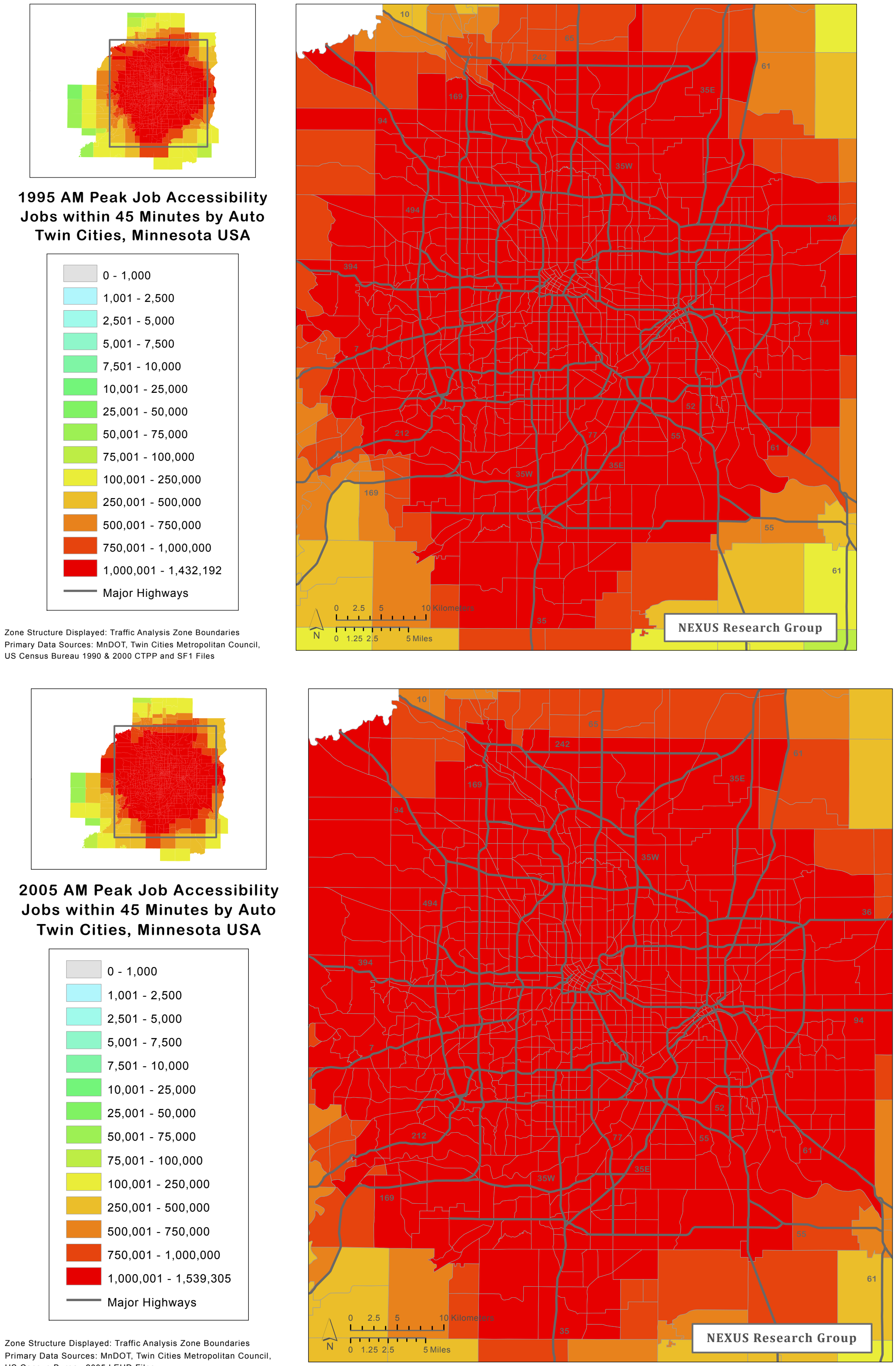


Figure 4.10: Jobs accessible within 45 minutes.

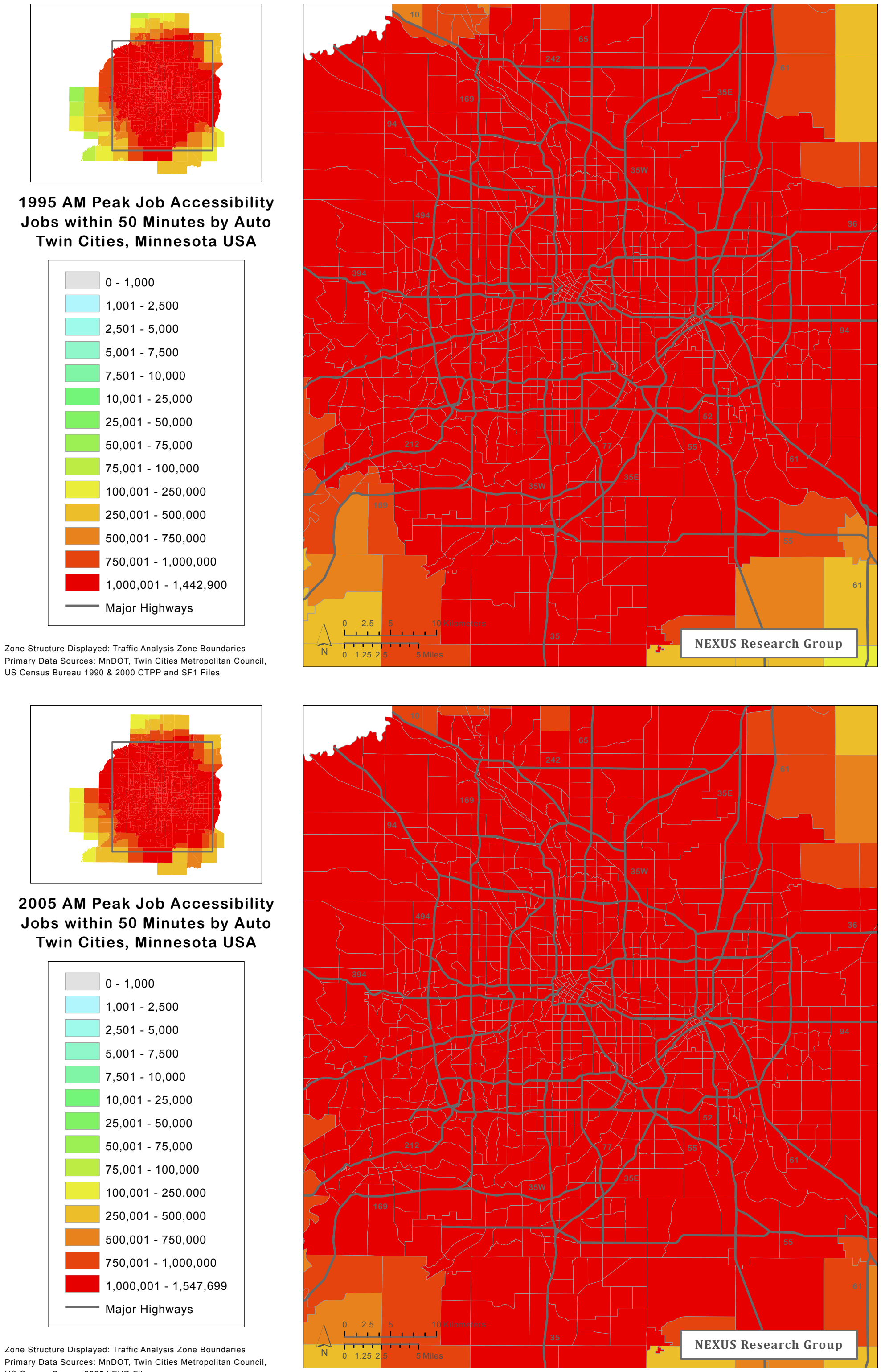


Figure 4.11: Jobs accessible within 50 minutes.

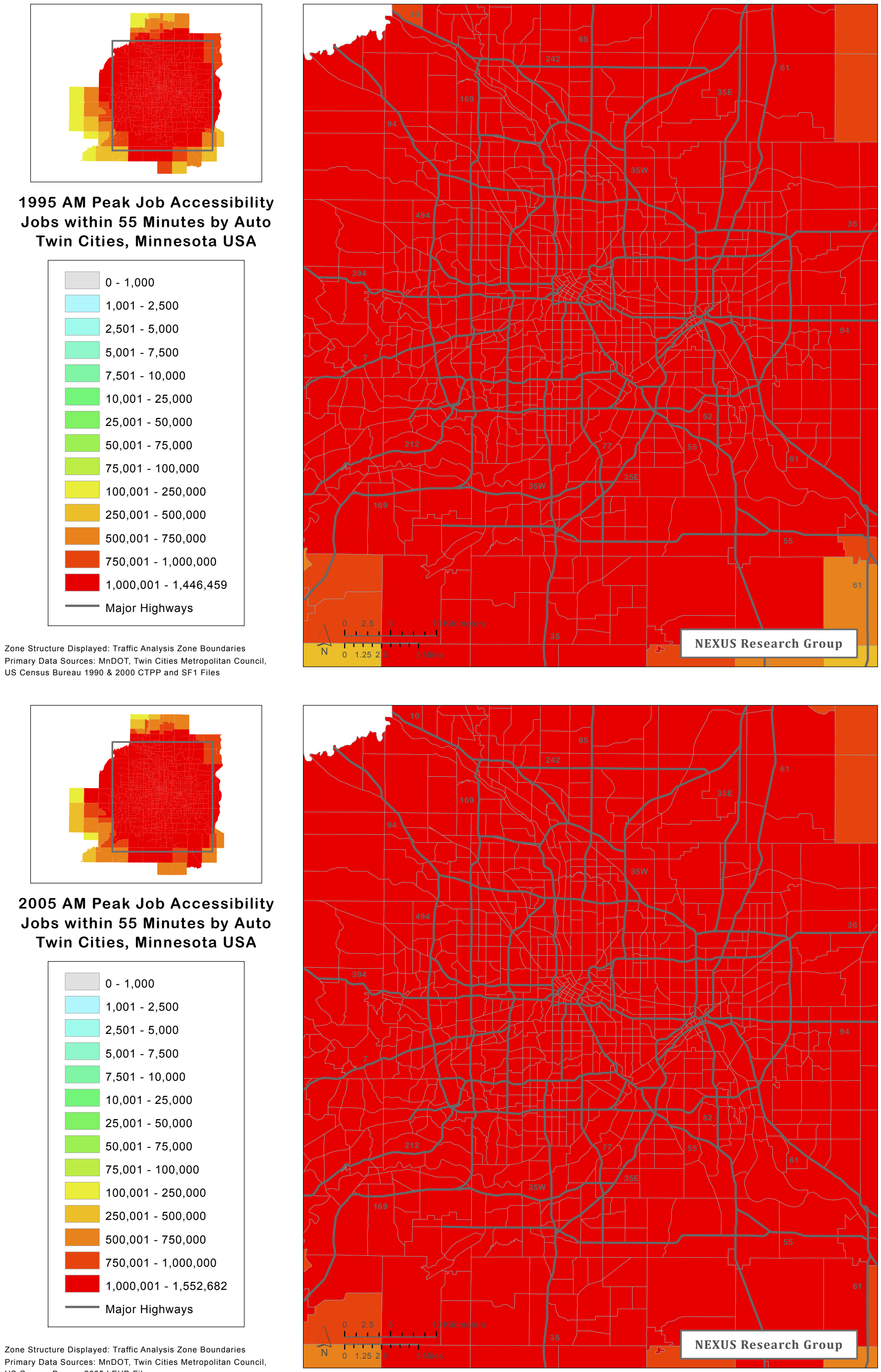


Figure 4.12: Jobs accessible within 55 minutes.

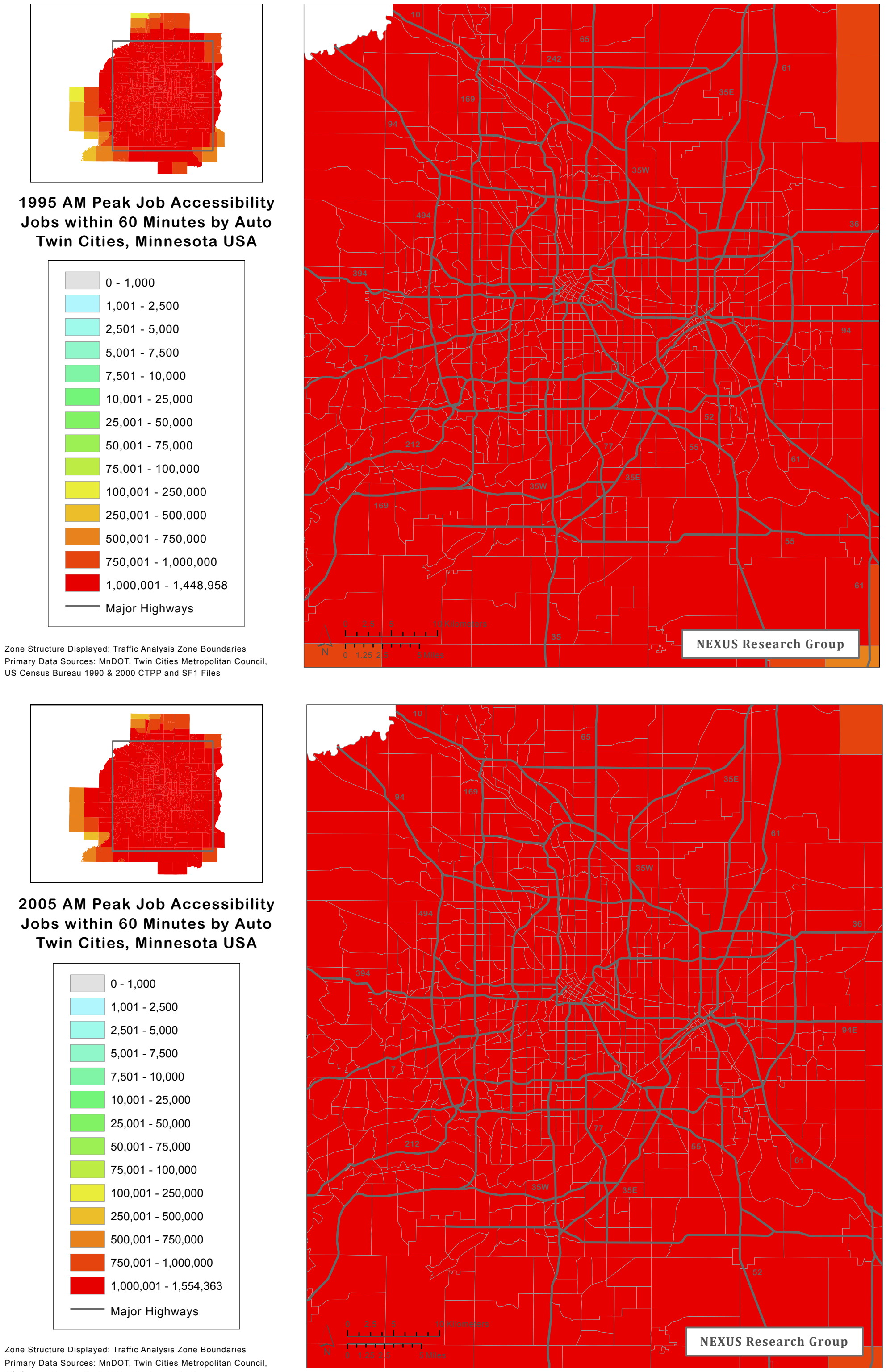


Figure 4.13: Jobs accessible within 60 minutes.

4.2 Difference Maps

The maps in this section show how accessibility to population, employment and labor changed across the region from 1995 to 2000 to 2005. The hypothesis was that accessibility is flattening over time; that is, the variance across the region between the zones with the most cumulative opportunities and those with the least is decreasing. As suburban and exurban areas grew at a faster pace than the central cities and development intensified along the I-494/I-694 beltway as compared to the cores of the cities, the expected results would show that accessibility also increased at a greater rate in outlying areas than in the central cities and first-ring suburbs. These are given in the Appendix.

4.3 Travel Time Contour Maps

A series of maps was created to show the extents in each direction that could be reached within a certain time from each TAZ in each of the three years studied. These maps can be compared with accessibility maps to illustrate how mobility, which does not account for density of destinations, compares with accessibility, which does. The points of interest chosen from around the region as bases for these maps are Southdale, Rosedale, Maple Grove, Woodbury, and Brooklyn Cener. These locations were selected to give residents of all corners of the metropolitan area some indication of how far they can travel within each time. The same travel time range and increment were used for this series as for the accessibility maps. These are given below.

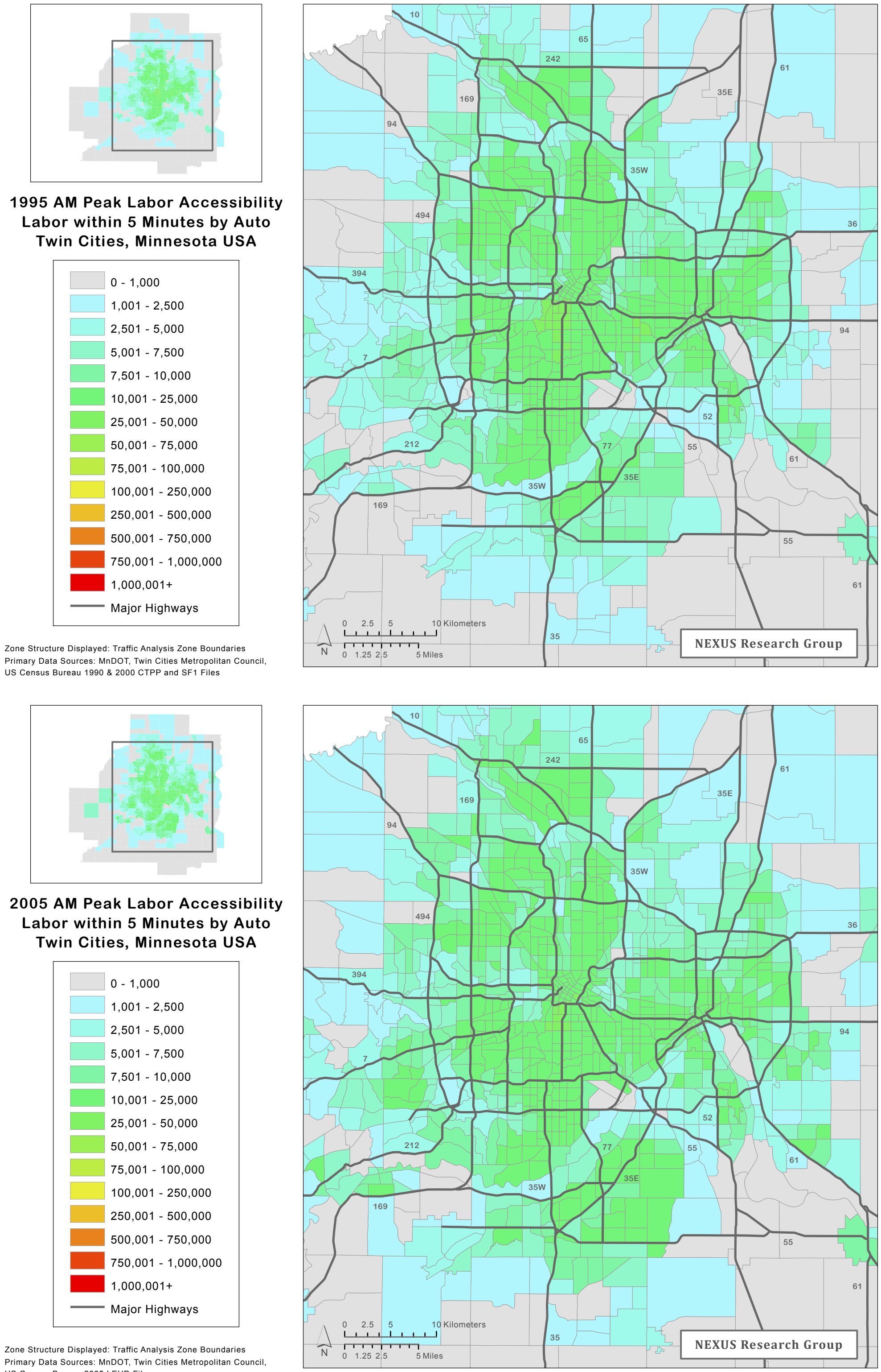


Figure 4.14: Workers accessible within 5 minutes.

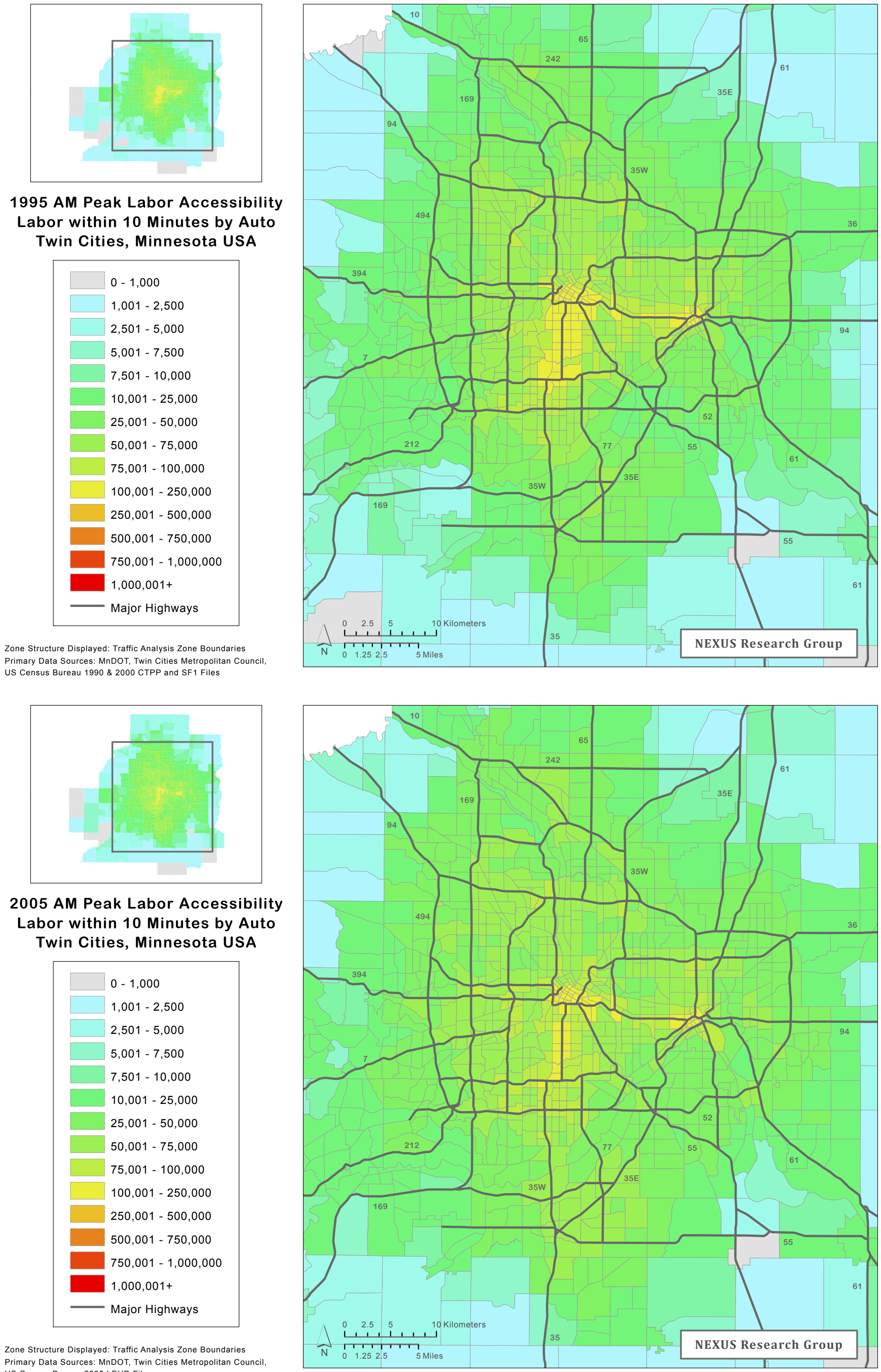


Figure 4.15: Workers accessible within 10 minutes.

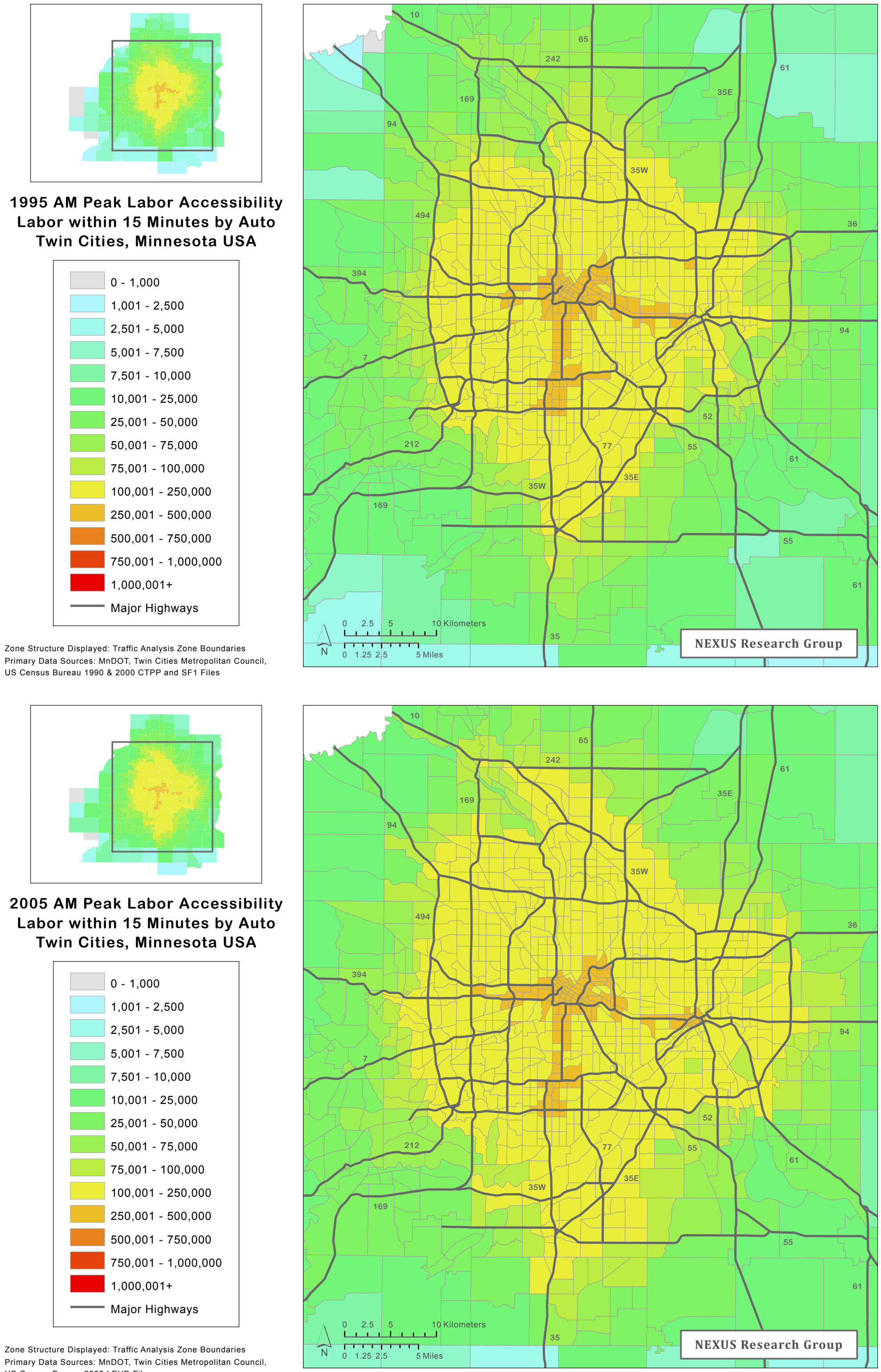


Figure 4.16: Workers accessible within 15 minutes.

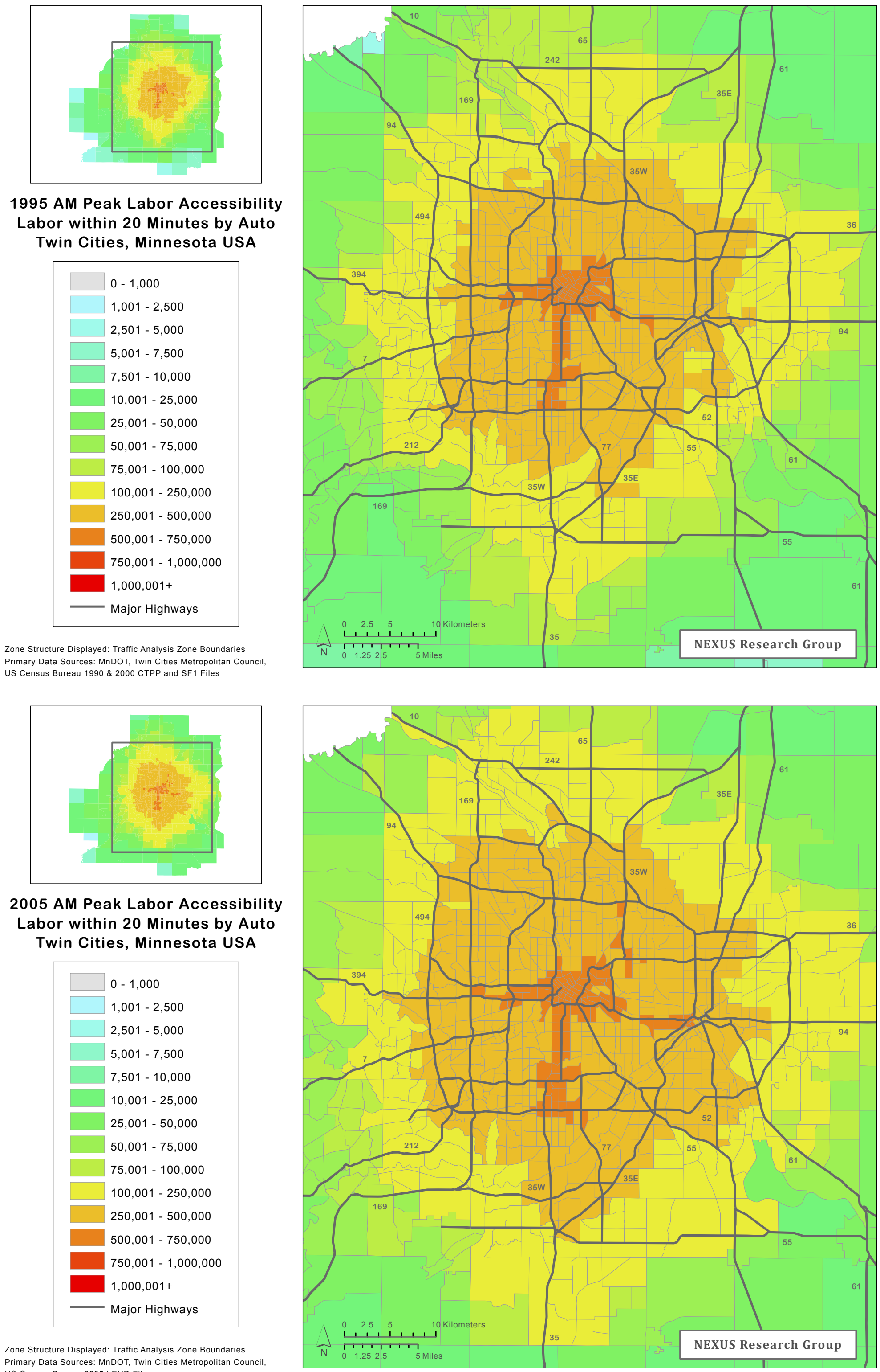


Figure 4.17: Workers accessible within 20 minutes.

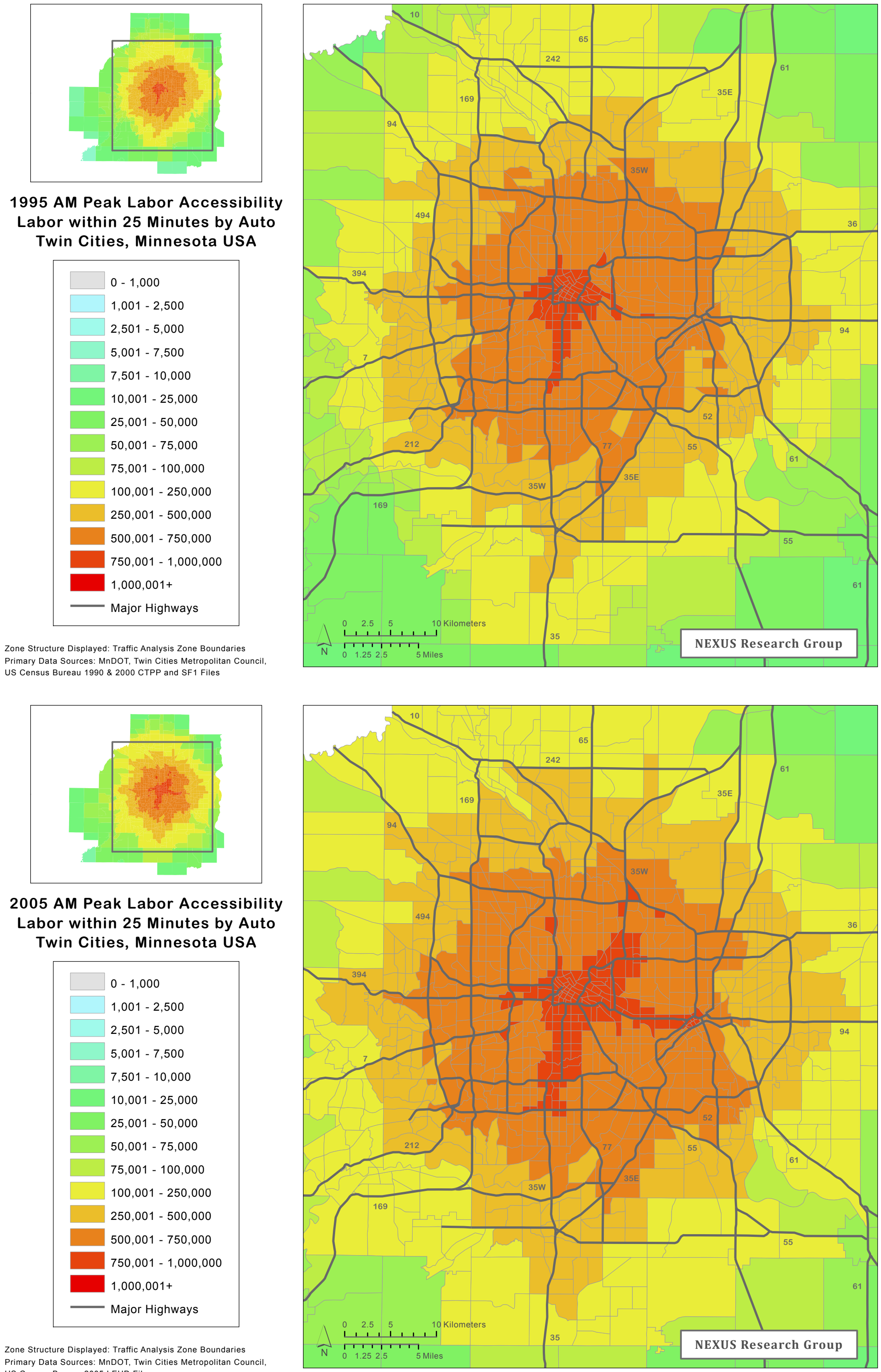


Figure 4.18: Workers accessible within 25 minutes.

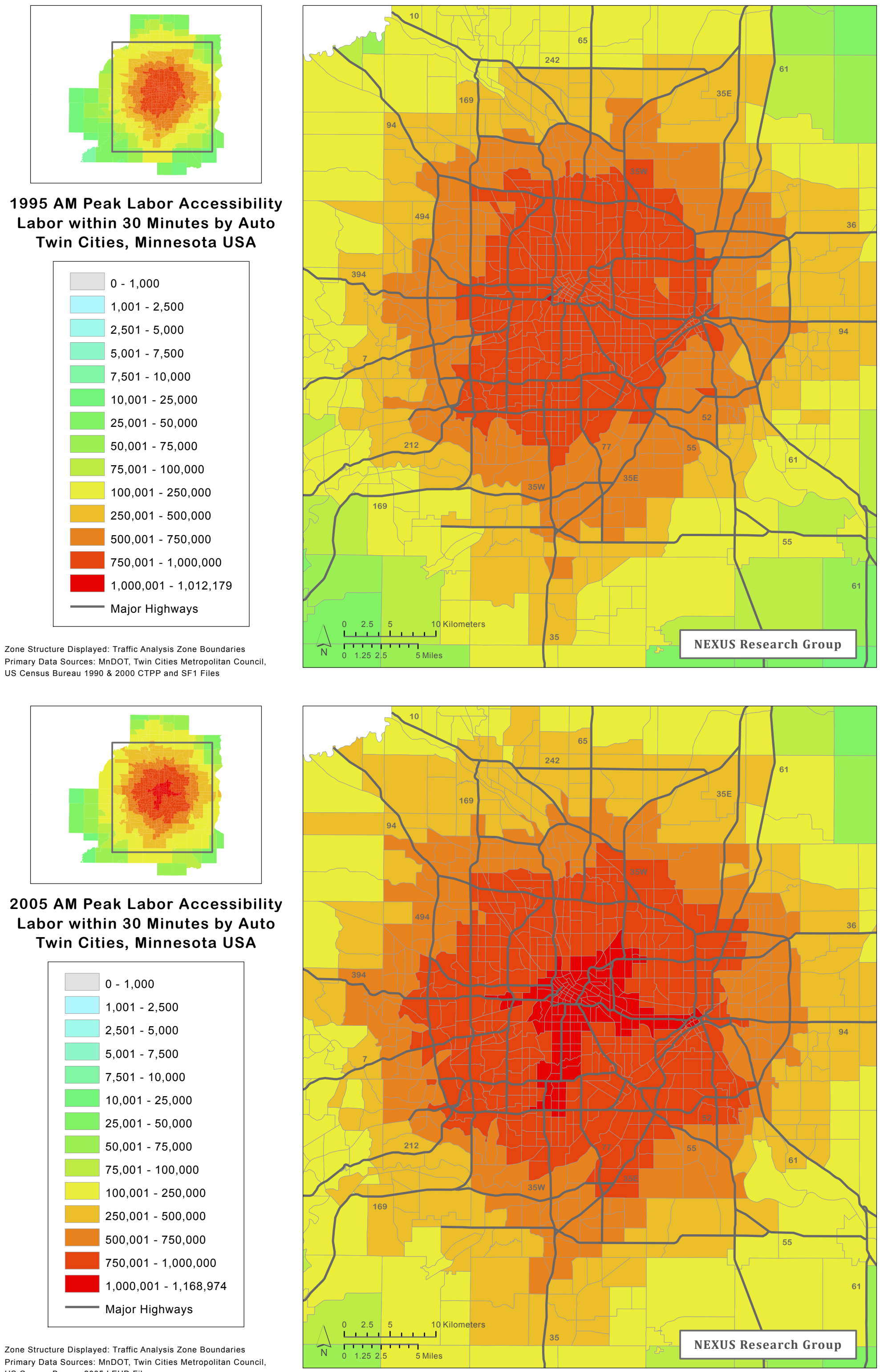


Figure 4.19: Workers accessible within 30 minutes.

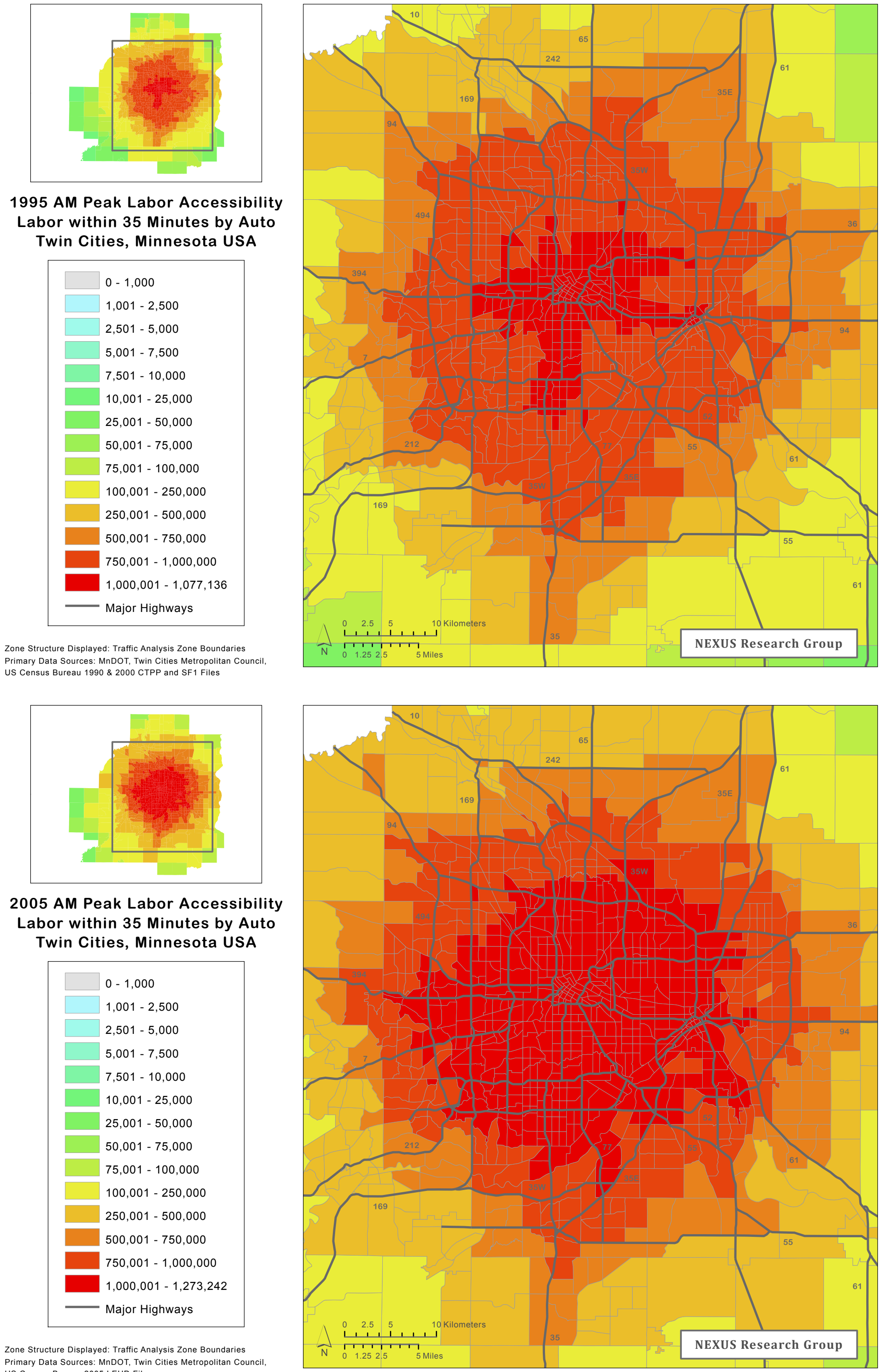


Figure 4.20: Workers accessible within 35 minutes.

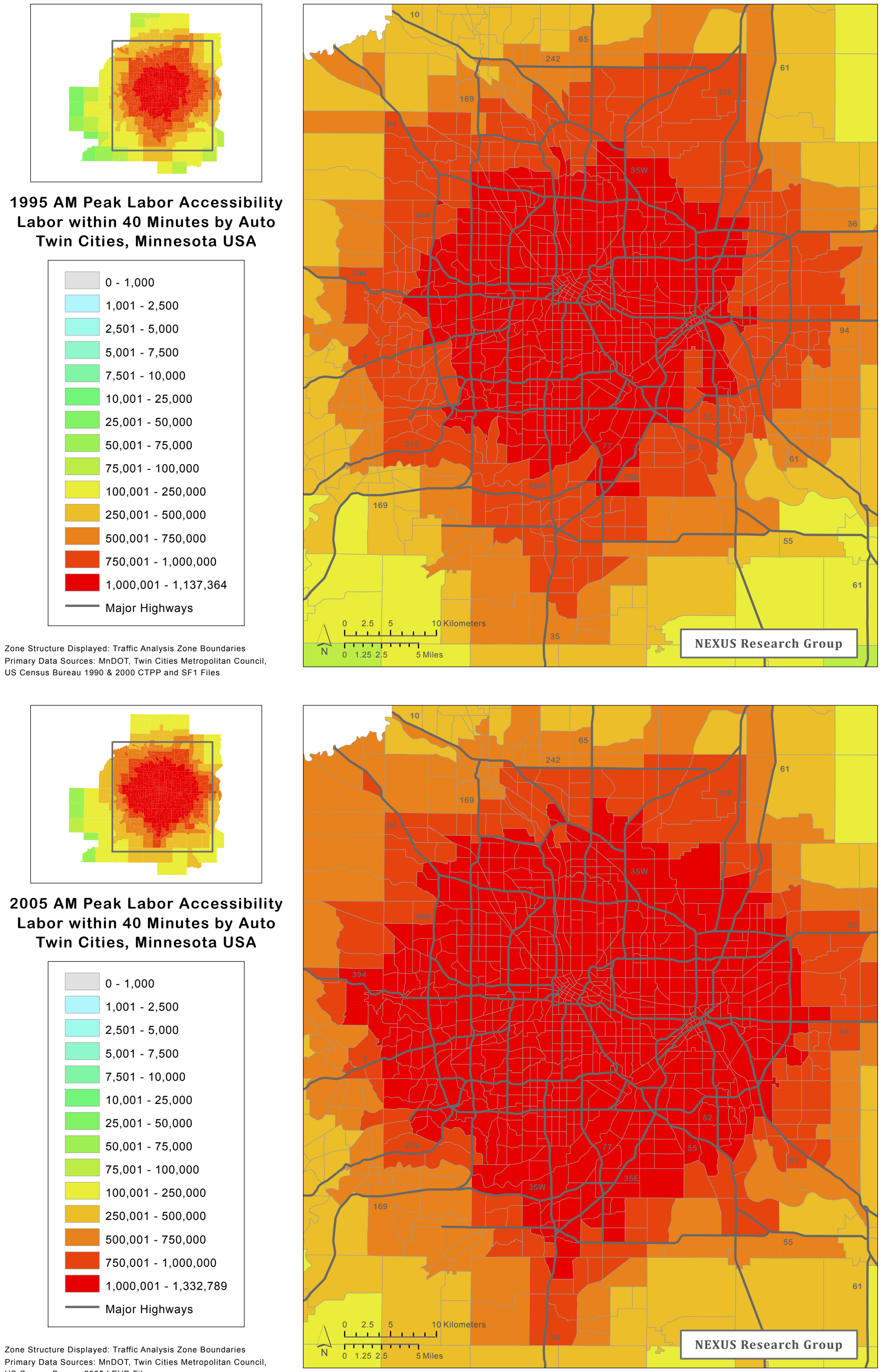


Figure 4.21: Workers accessible within 40 minutes.

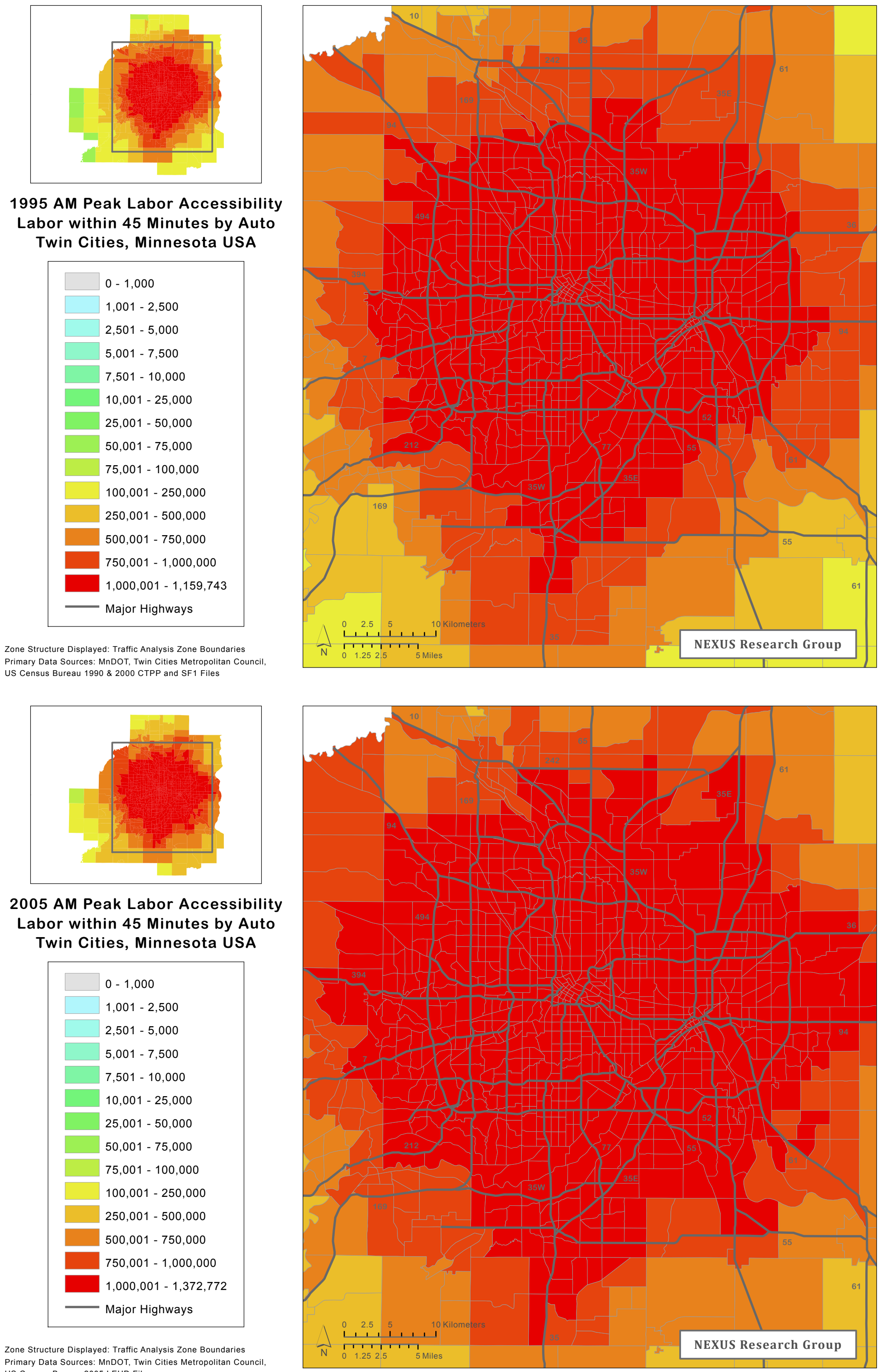


Figure 4.22: Workers accessible within 45 minutes.

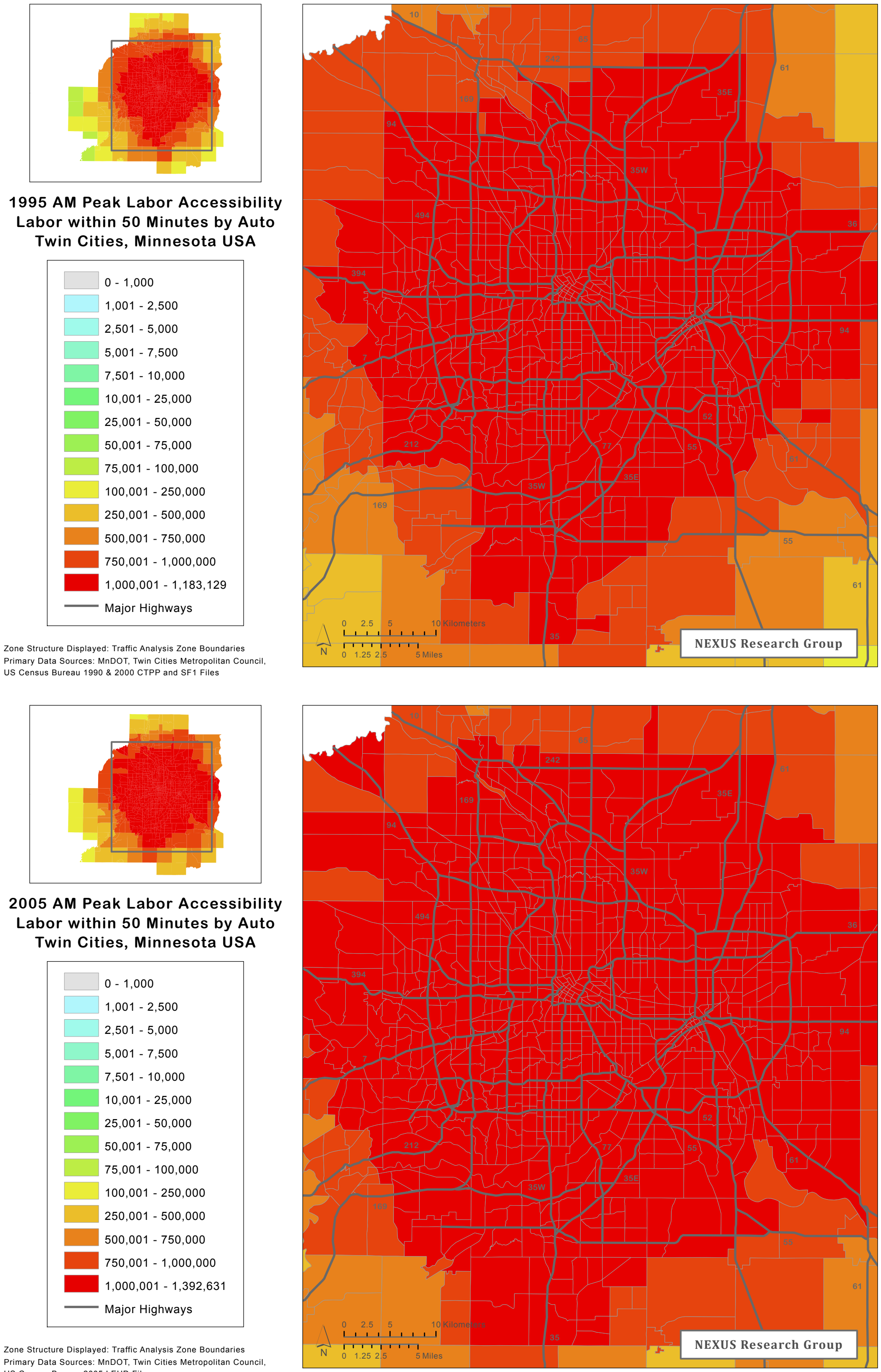


Figure 4.23: Workers accessible within 50 minutes.

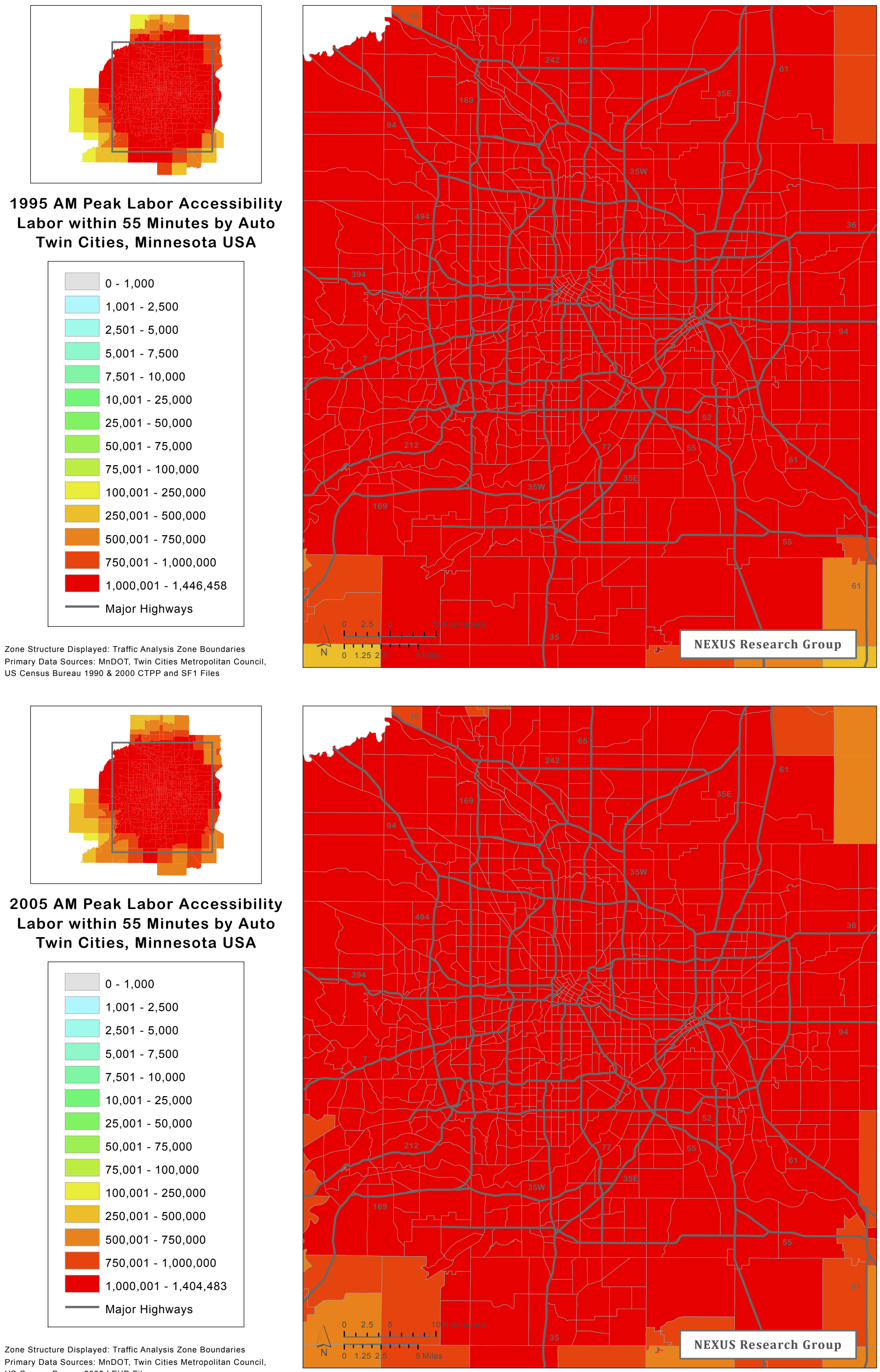


Figure 4.24: Workers accessible within 55 minutes.

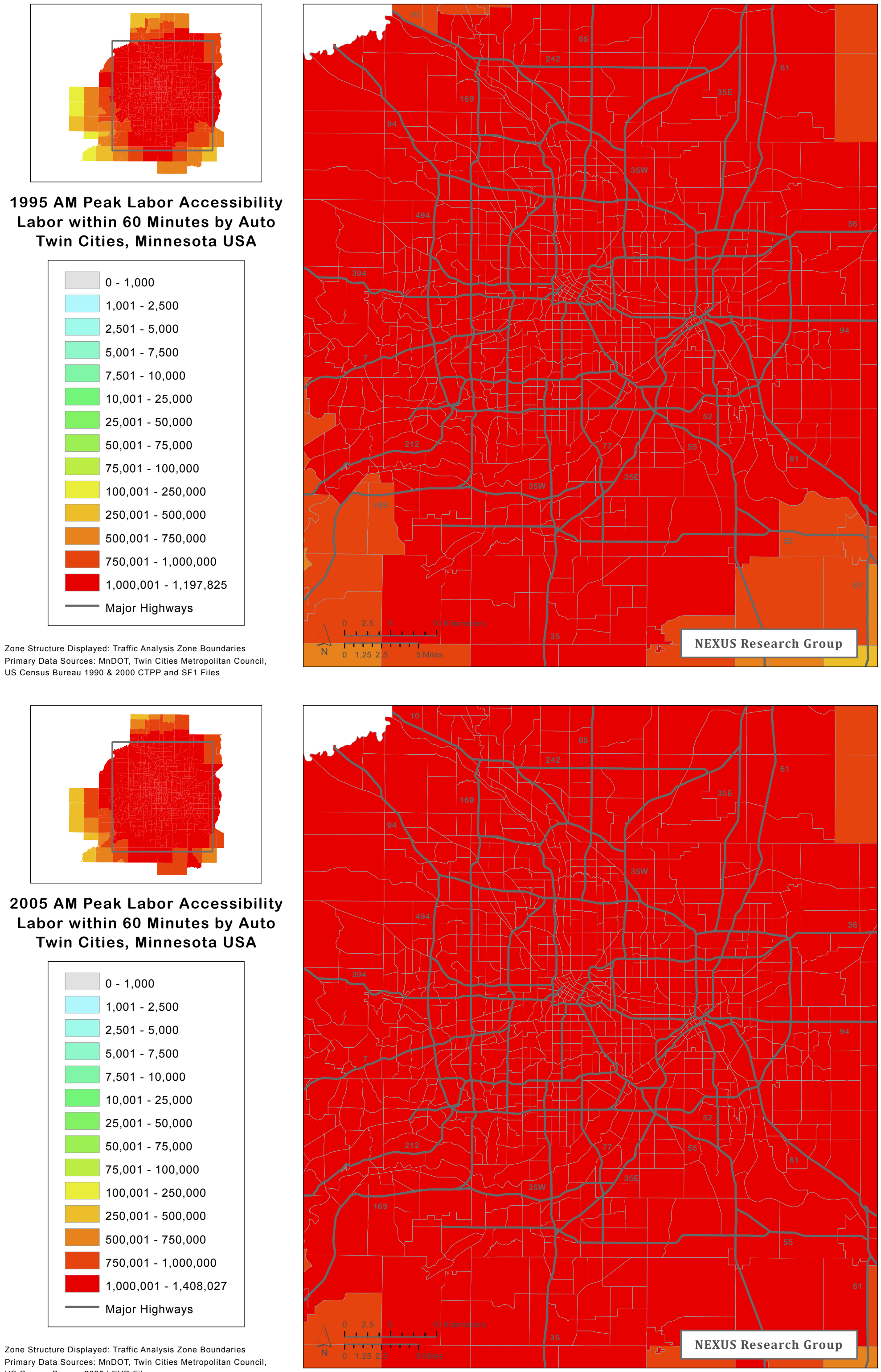


Figure 4.25: Workers accessible within 60 minutes.

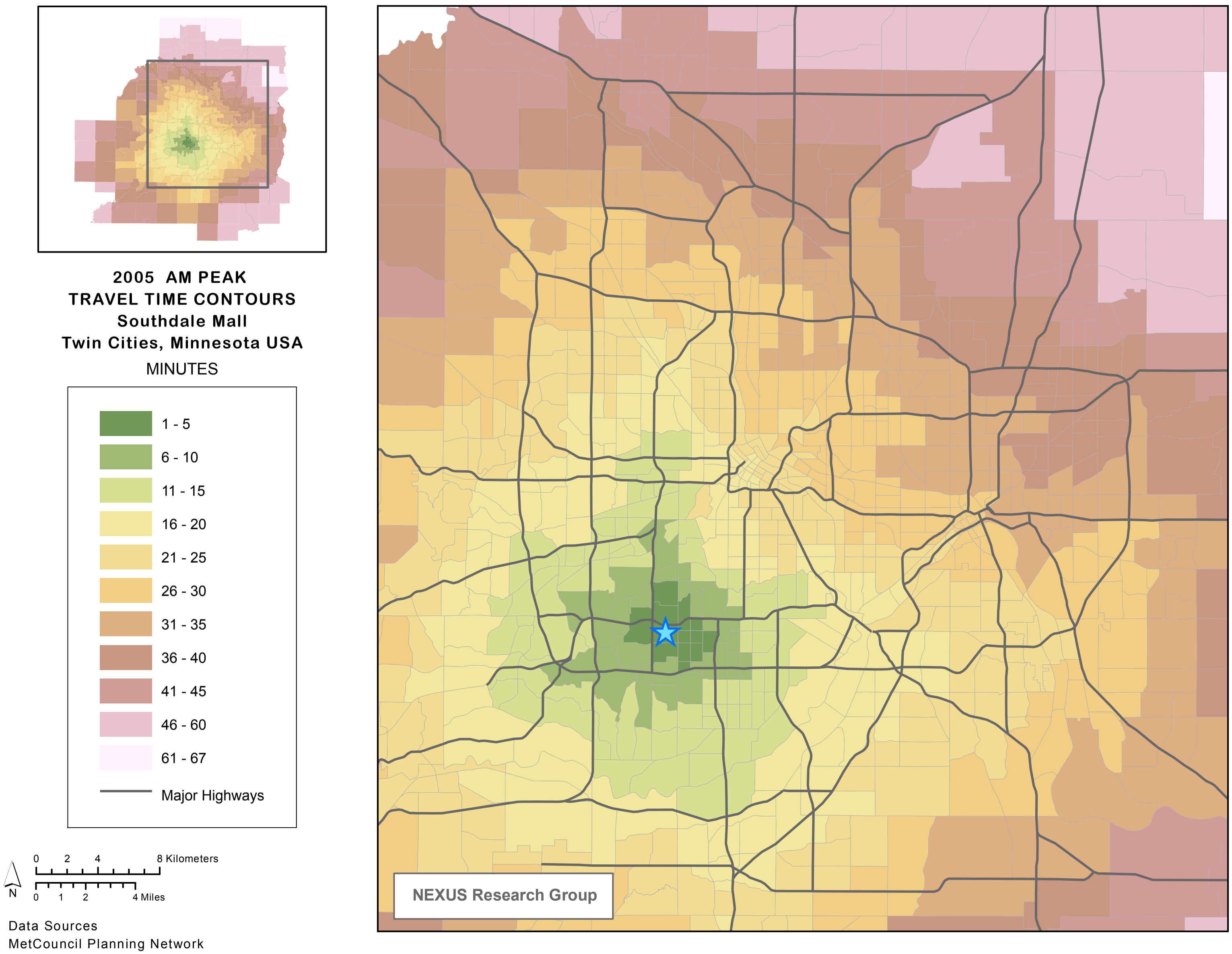


Figure 4.26: Travel time contour, Southdale Mall, A.M. peak.

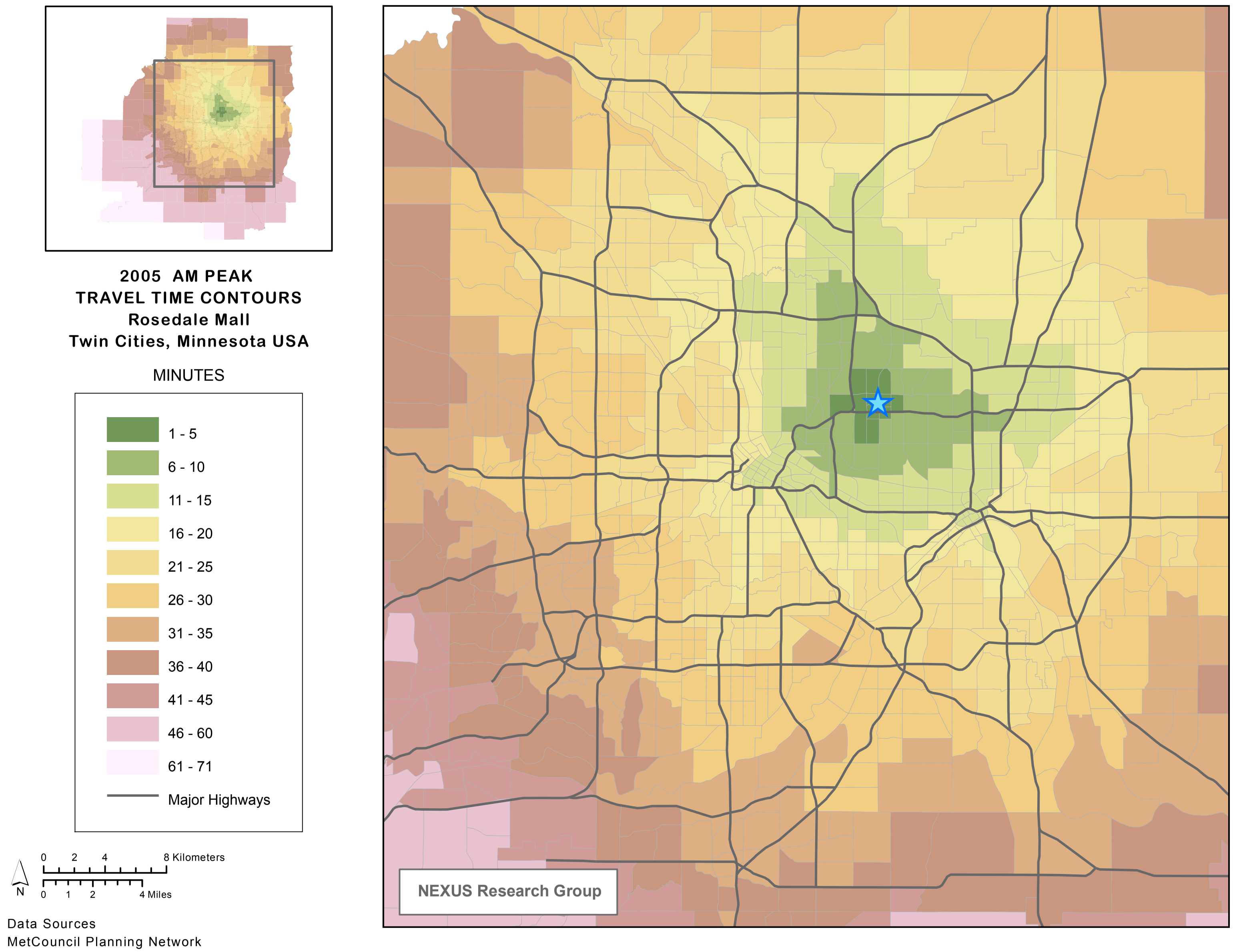


Figure 4.27: Travel time contour, Rosedale Mall, A.M. peak.

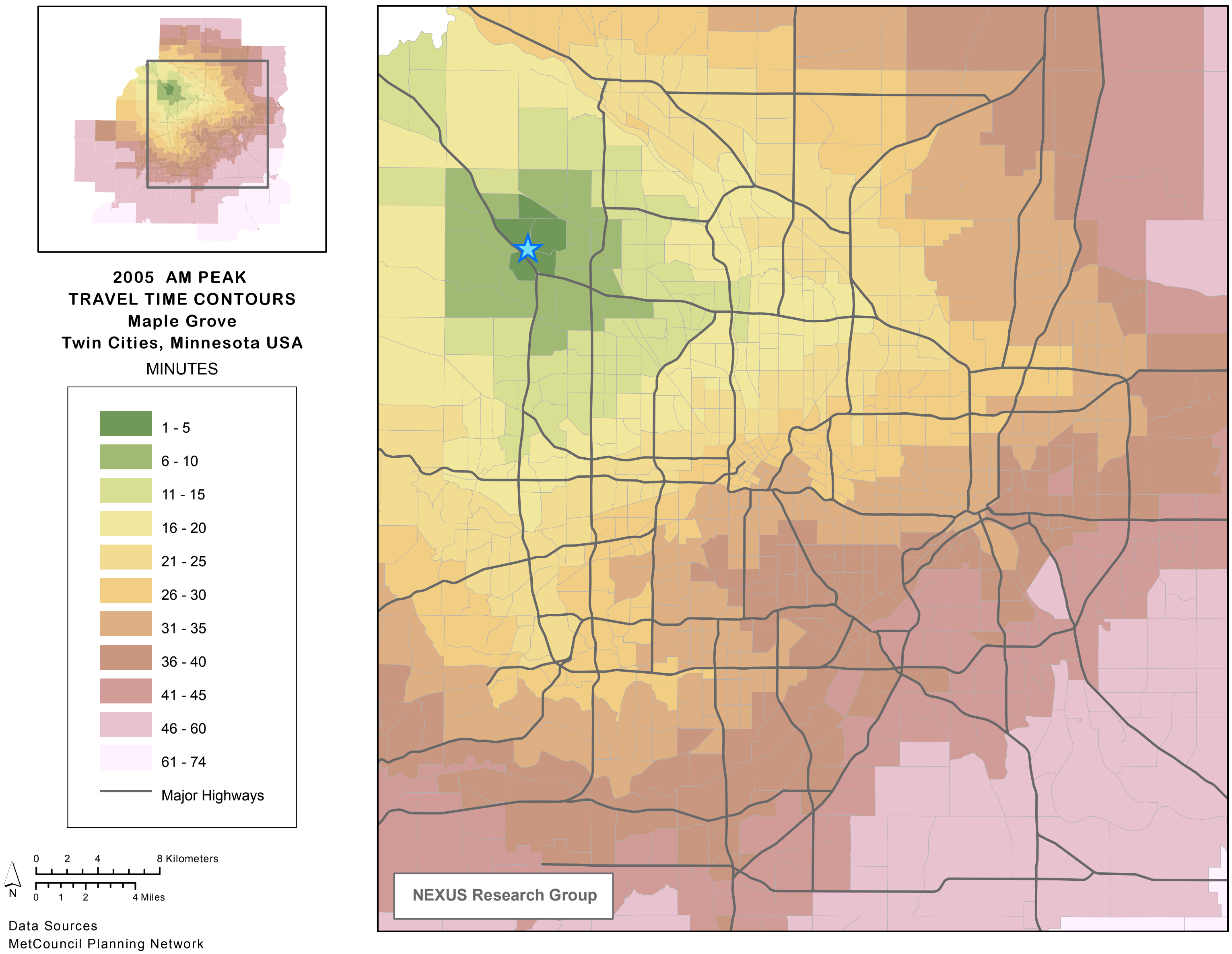


Figure 4.28: Travel time contour, Maple Grove, A.M. peak.

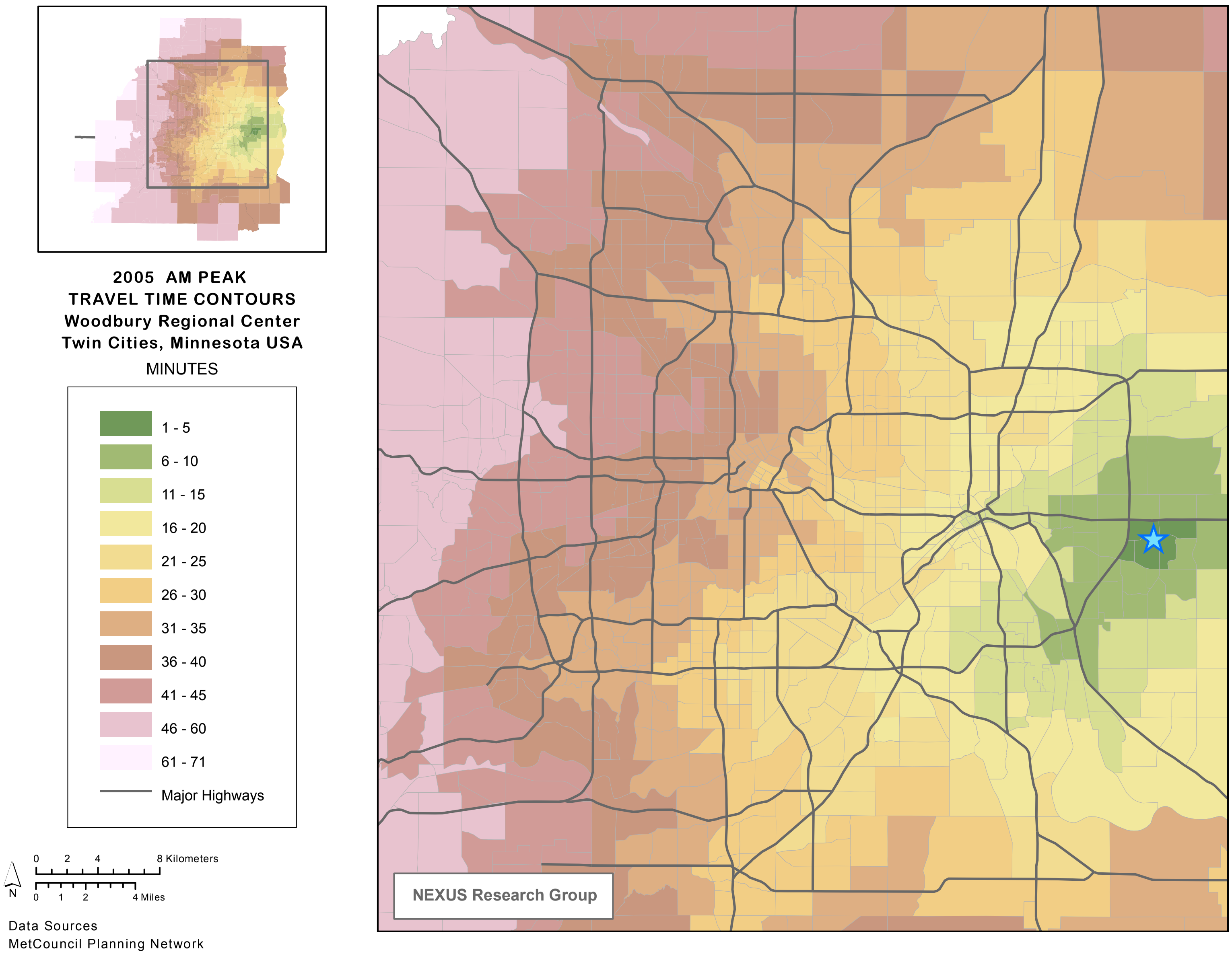


Figure 4.29: Travel time contour, Woodbury, A.M. peak.

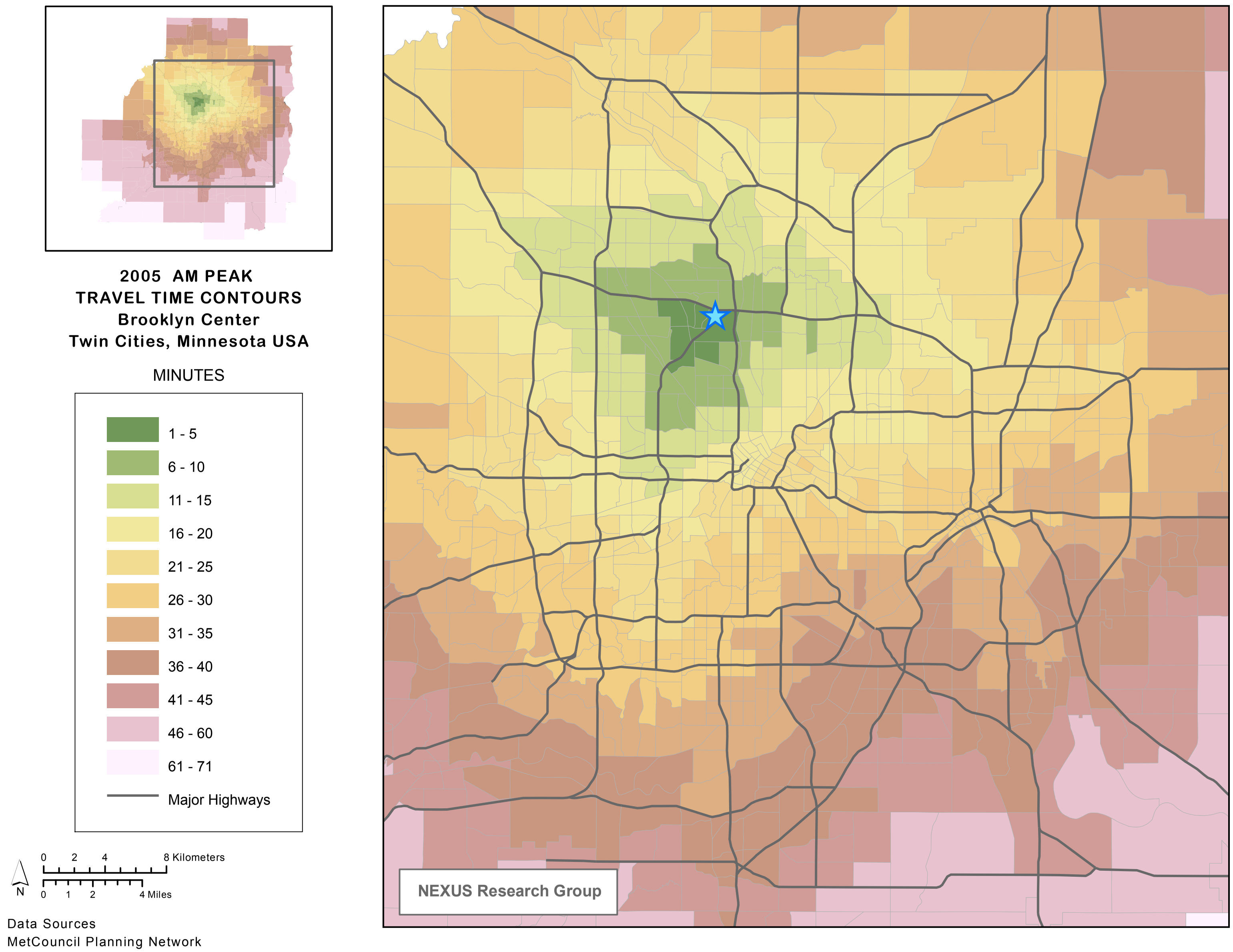


Figure 4.30: Travel time contour, Brooklyn Center, A.M. peak.

4.4 Standard Deviational Ellipse Analysis (SDE)

Although the previous analysis of the 20 minute commute-time threshold reveals many trends, including those that suggest that the city is indeed getting flatter, there is still an opportunity to further generalize accessibility outcomes for trend analysis. The Standard Deviational Ellipse (SDE) measure complements our discussion of accessibility differences across space. The tool is most commonly used to identify hot spots of crime events; however it used in numerous other types of studies as a method for spatially descriptive exploration. Both the dispersion and orientation of the dispersion of events are described by the generated ellipse. Thus, SDE is particularly effective at capturing the directionality bias of the location of events in any direction including intermediate compass directions around the mean center. For a set of geographical coordinates, the ellipse is calculated by first finding the mean center of events, which is located at the intersection of the average of X coordinate values and the average of Y coordinate values. The length of each axis is defined by the standard deviation of the distribution of values from the mean respectively. A higher standard value implies a larger dispersion of events on that axis. The ratio of the two axes yield a measure of circularity. The circularity of the ellipse is also useful for understanding whether the reach of accessibility is, in a crude way, flat. A low degree of circularity implies that the location of events described by the (SDE) are tightly dispersed along a directional path. So, for example, a measure of circularity allows the user to ascertain whether high accessibility events are associated with any one particular transportation corridor. When considering all of these factors, SDE appears an ideal means by which to understand the distribution of accessibility inequality within the urban system.

Figures 4.31, 4.32, 4.33, 4.34 show the SDE for access within 20 minutes to jobs and workers to 100,000, 250,000, 500,000 and 750,000 respectively. As can be seen from these figures, the city is indeed getting flatter at the 20 minute level, the 2005 SDE is larger, and almost completely encloses each 1995 ellipse.

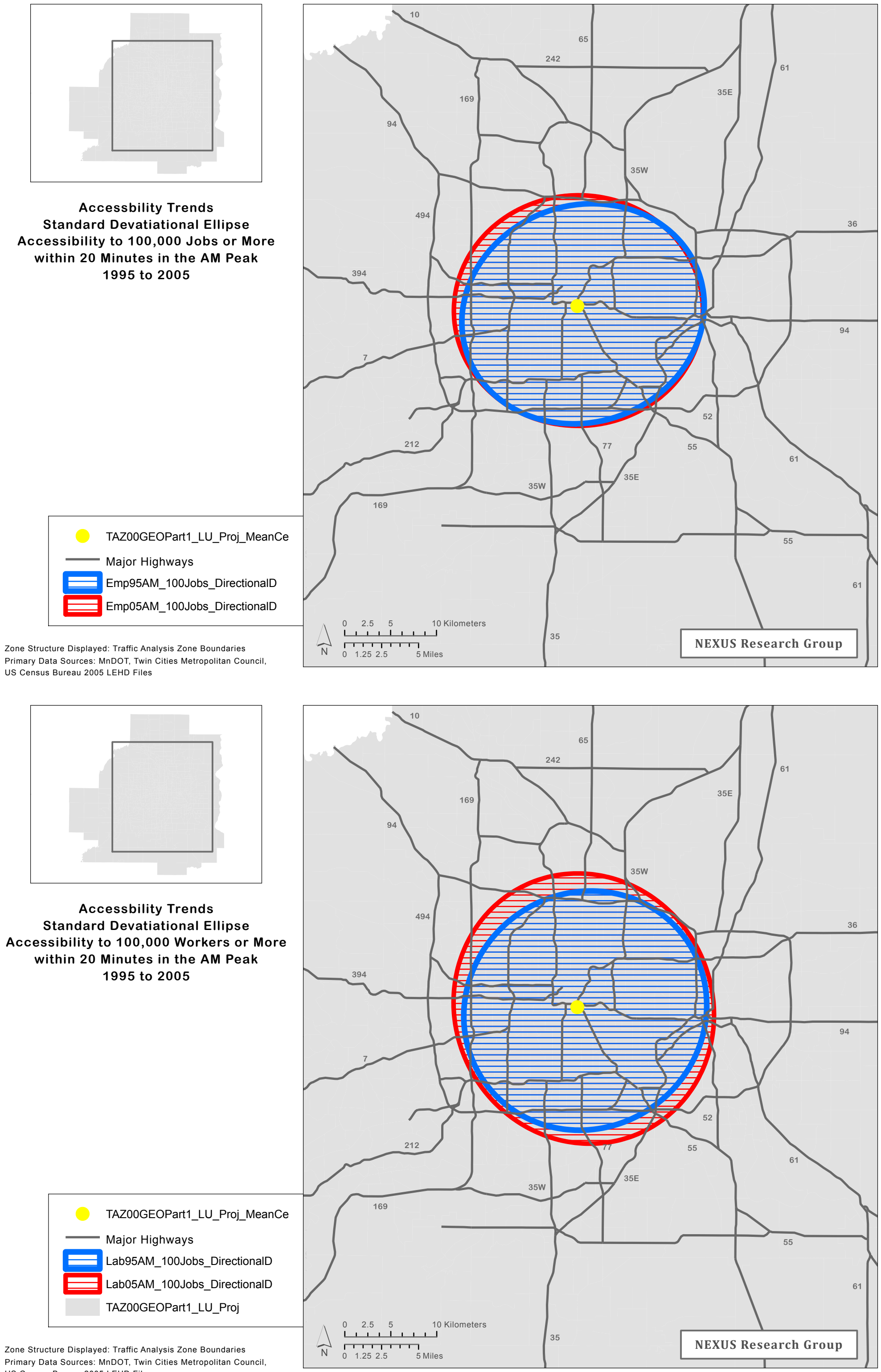


Figure 4.31: Standard deviational ellipse for access within 20 minutes to 100,000 jobs and workers (2005 and 1995) in the A.M. peak period

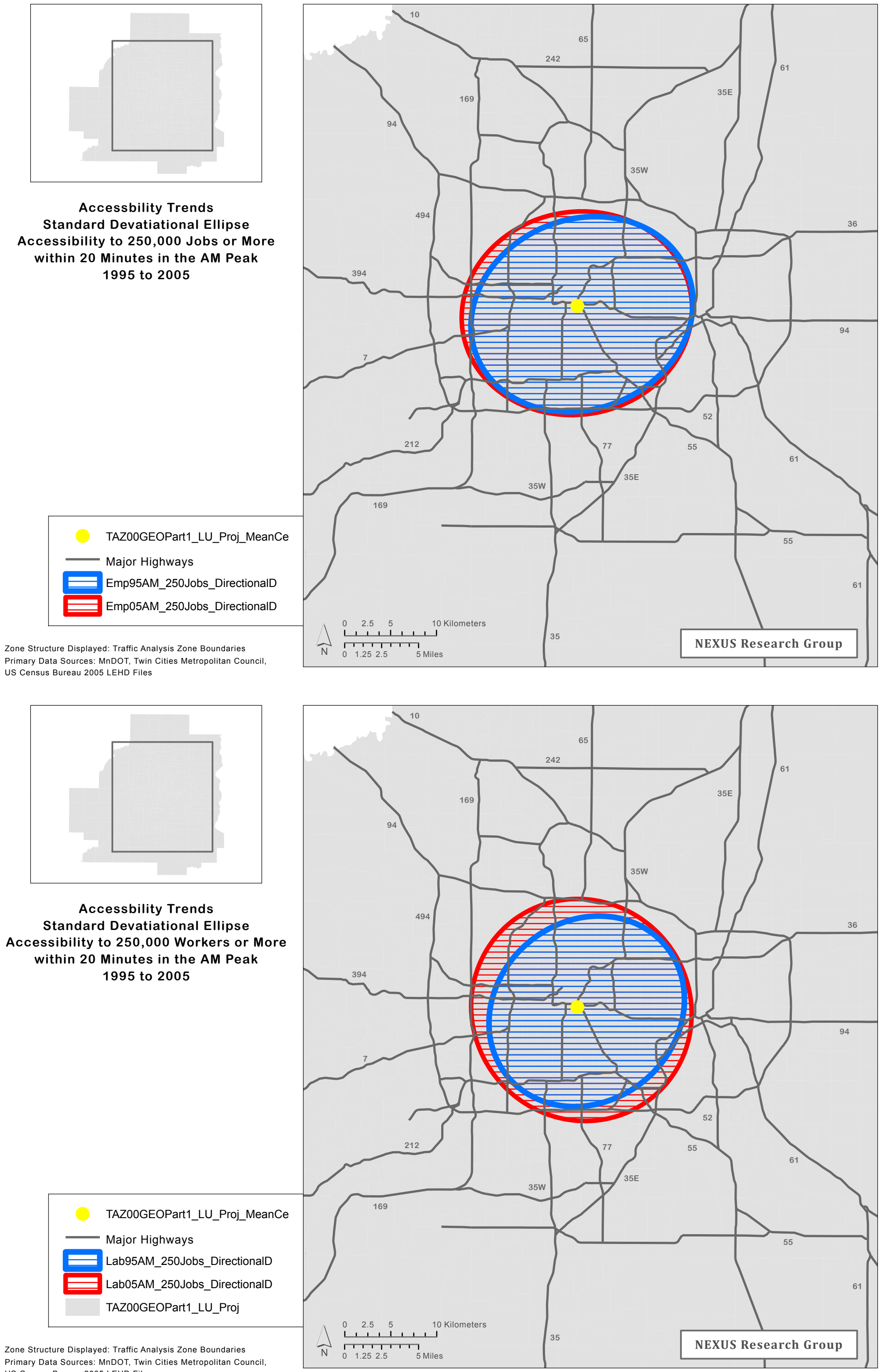


Figure 4.32: Standard deviational ellipse for access within 20 minutes to 250,000 jobs and workers (2005 and 1995) in the A.M. peak period

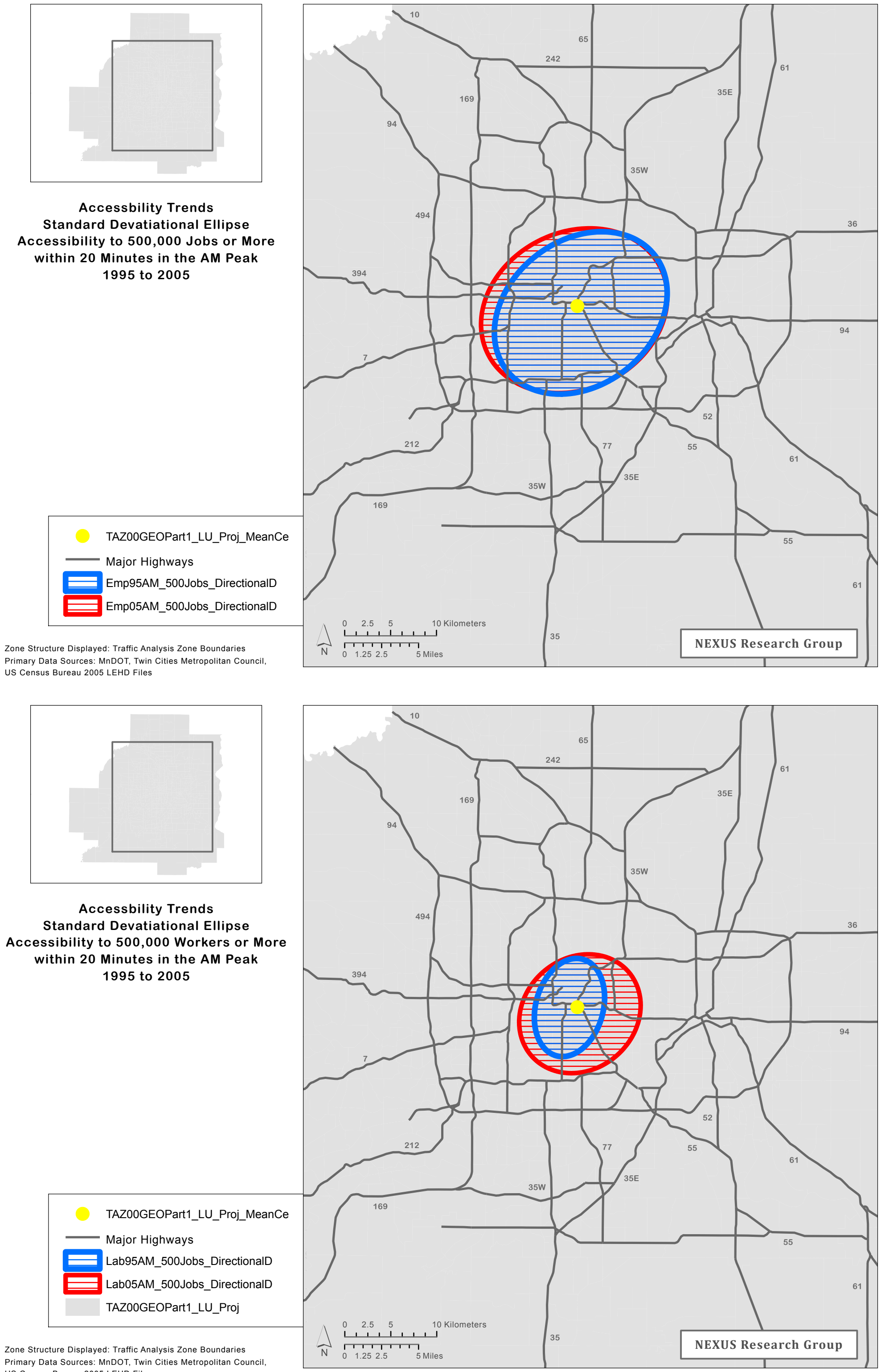


Figure 4.33: Standard deviational ellipse for access within 20 minutes to 500,000 jobs and workers (2005 and 1995) in the A.M. peak period

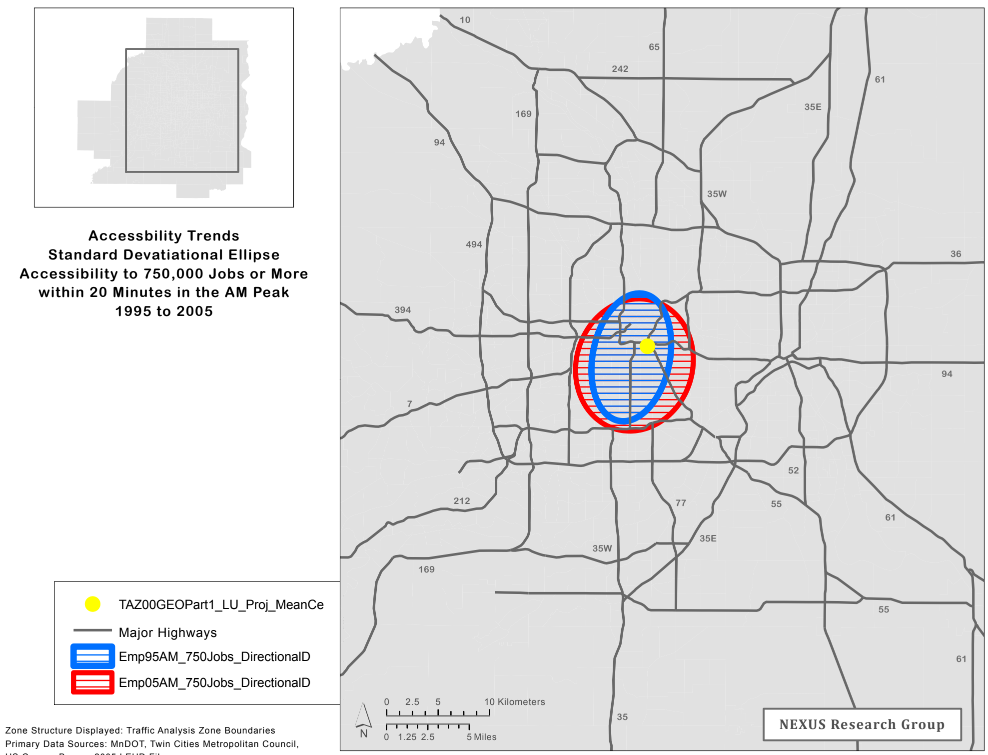


Figure 4.34: Standard deviational ellipse for access within 20 minutes to 750,000 jobs (2005 and 1995) in the A.M. peak period

Table 4.1: Spatial distribution and standard deviational ellipse analysis (SDE) area differences: accessibility to jobs, 20 minutes.

year	land use	accessibility	area sq. miles / sq. km
JOBS			
1995		100K +	758 / 1963
2005		100K +	852 / 2207
1995		250K +	460 / 1190
2005		250K +	514 / 1331
1995		500K +	232 / 600
2005		500K +	260 / 674
1995		750K +	42 / 109
2005		750K +	68 / 177
1995		1M +	.05 / .12
2005		1M +	3 / 7
WORKERS			
1995		100K or more	773 / 2001
2005		100K +	1009 / 2615
1995		250K +	348 / 902
2005		250K +	464 / 1202
1995		500K +	30 / 109
2005		500K +	41 / 177

Table 4.2: Standard deviation ellipse analysis of accessibility to jobs

year	accessibility	x-axis length miles / km	y-axis length miles / km	area of ellipse sq. miles / sq. km	circularity
JOBS					
1995	100K +	7.34 / 11.81	8.34 / 13.37	192 / 496	0.88
2005	100K +	7.80 / 12.56	8.43 / 13.57	207 / 535	0.93
1995	250K +	6.42 / 10.34	7.68 / 12.36	191 / 401	0.84
2005	250K +	6.86 / 11.04	7.83 / 12.60	169 / 437	0.88
1995	500K +	4.91 / 7.91	6.35 / 10.22	98 / 254	0.77
2005	500K +	5.31 / 8.54	6.54 / 10.52	109 / 282	0.81
1995	750K +	2.33 / 2.33	3.91 / 6.29	29 / 74	0.60
2005	750K +	3.51 / 3.51	4.04 /6.49	45 / 115	0.87
WORKERS					
1995	100K +	7.96 / 12.81	8.36 / 13.46	209 / 542	0.95
2005	100K +	9.25 / 14.88	8.72 / 14.03	253 / 656	0.94
1995	250K +	6.10 / 9.82	6.94 / 11.17	133 / 345	0.88
2005	250K +	7.62 / 12.27	7.36 / 11.85	176 / 457	0.97
1995	500K +	2.29 / 3.68	3.39 / 5.45	24 / 63	0.67
2005	500K +	3.77 / 6.07	4.35 / 7.00	52 / 134	0.87

4.5 Job / Worker Balance

Employment remains much more concentrated than labor. Recognizing that, at the metropolitan level, the number of jobs essentially equals the number of workers, access to jobs is much more highly peaked in city centers than access to labor is (though the peak locations are very close). Over this period, the center of gravity of employment has moved westward (in the south-southwest direction), while the center of gravity of labor has moved less so. Labor has continued to suburbanize, more so in the directions North and South of Minneapolis, and less directly due west. A ratio of jobs to labor (which equals 1.0 at the regional level) shows where job access exceeds labor access, and where the converse is true. Overall the region is becoming more balanced at the longer time bands (though less balanced locally).

Figure 4.35 shows job to worker ratio at a 15 minute timeband for 1995 and 2005. The areas in dark red indicate areas with the greatest ratio of jobs to workers. These areas tend to surround downtown, but have migrated from 1995 to 2005. The areas in dark blue indicate the areas with the lowest ratio, which tend to be at the edge of the region.

As might be expected, at a 20 minute bandwidth, Figure 4.36, areas are in greater balance and fewer traffic zones show extreme values. The general pattern is similar for the two years.

By a 25 minute bandwidth (the bandwidth closest to average commuting times in the Twin Cities, about 24 minutes), shown in Figure 4.37, more area is light blue or yellow, indicating greater balance, and balance is greater in 2005 than 1995. The areas of greatest imbalance are along the I-394 corridor and along the Hiawatha Avenue Corridor.

Finally, considering a 30 minute bandwidth, shown in 4.38, balance is significantly increased between 1995 and 2005.

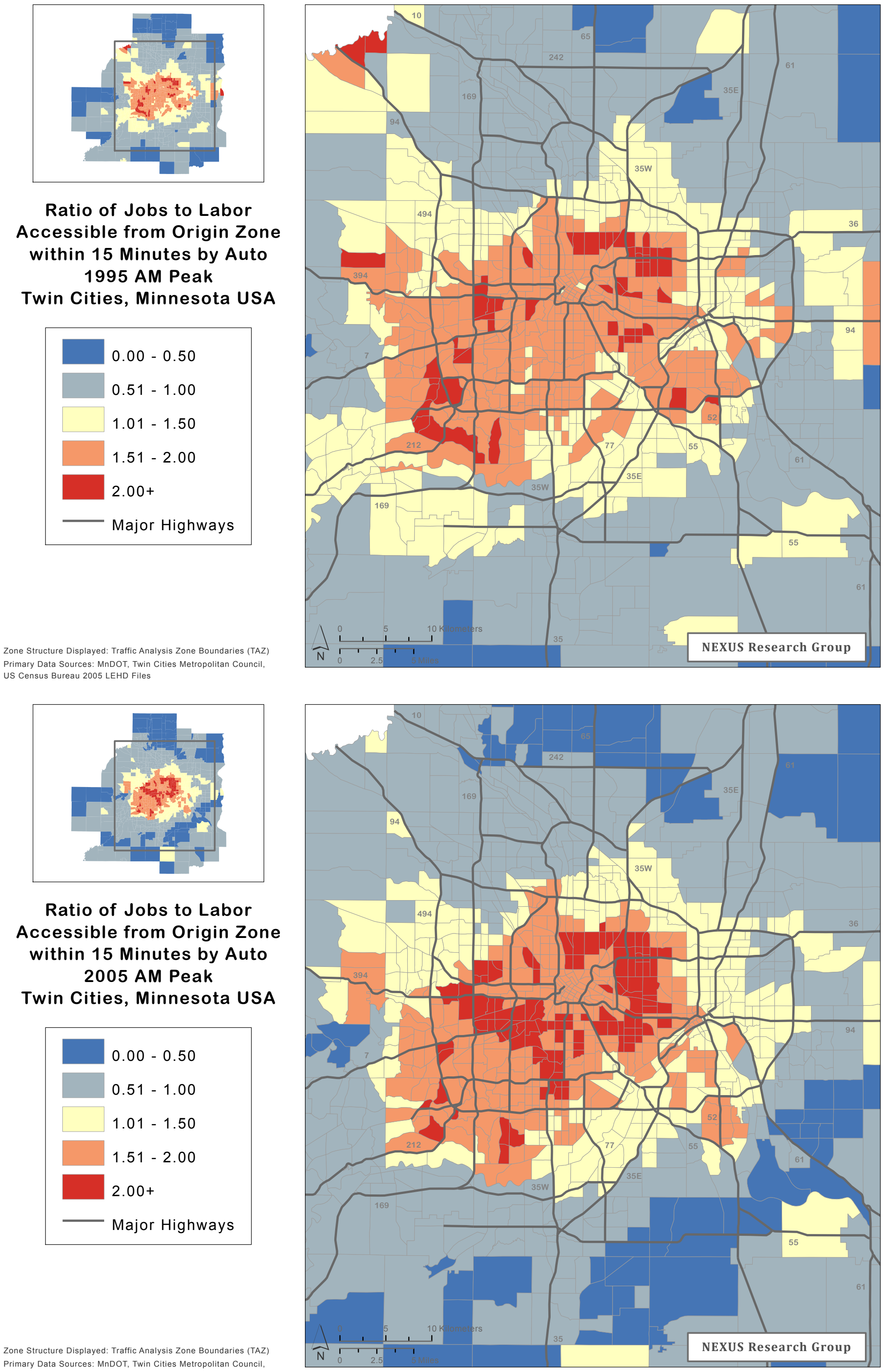


Figure 4.35: Job / worker ratio at 15 minutes.

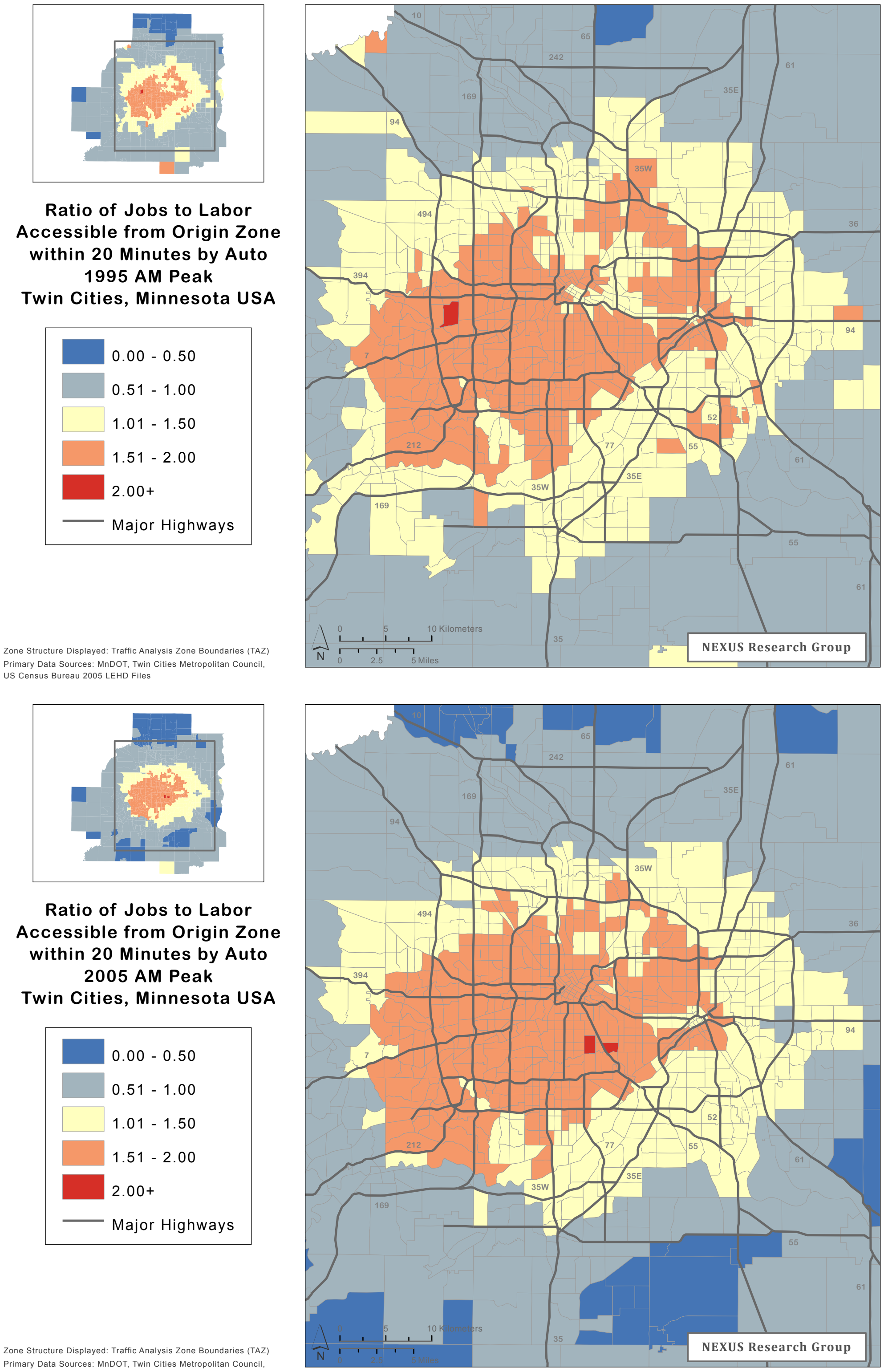


Figure 4.36: Job / worker ratio at 20 minutes.

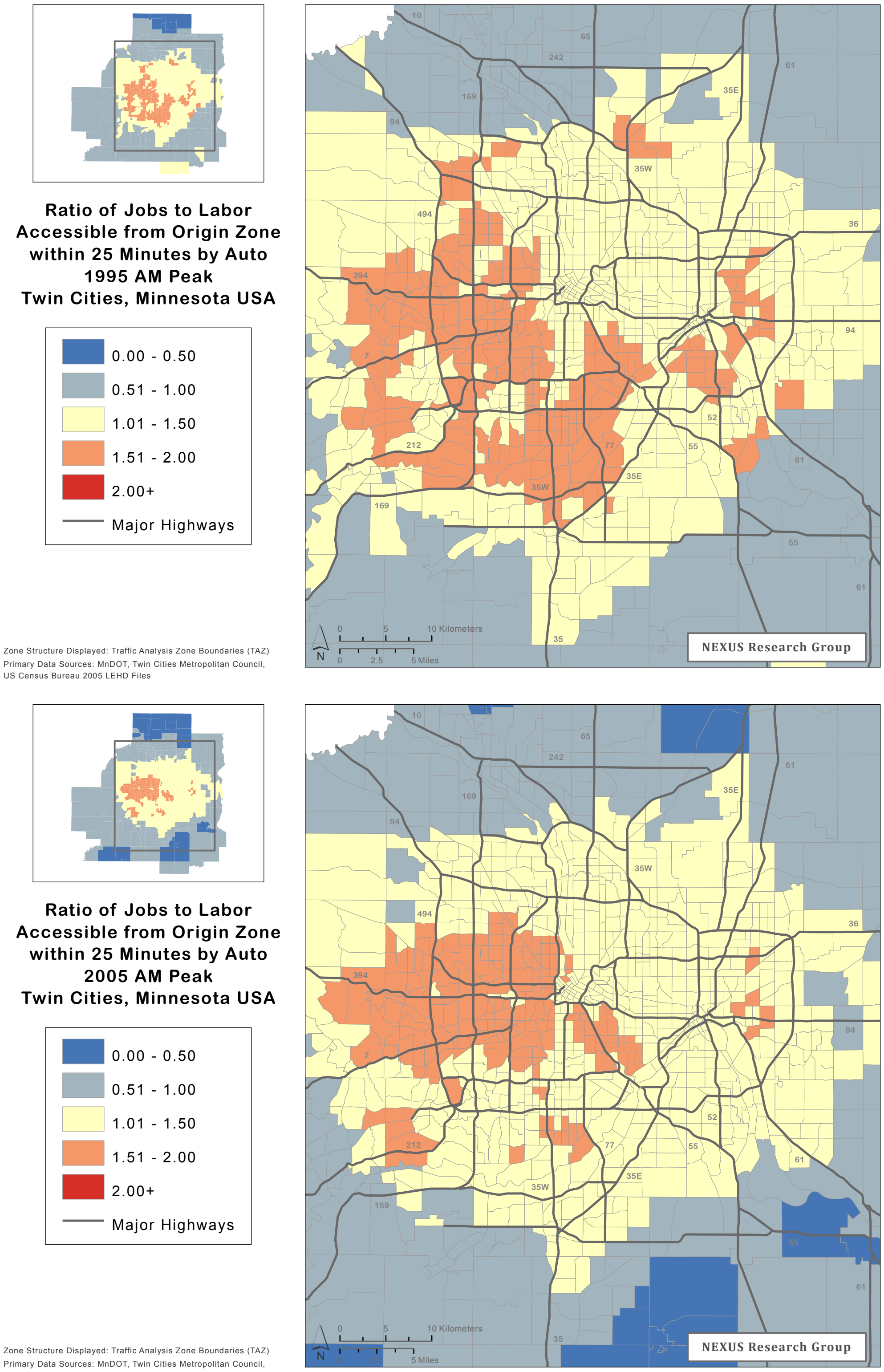


Figure 4.37: Job / worker ratio at 25 minutes.

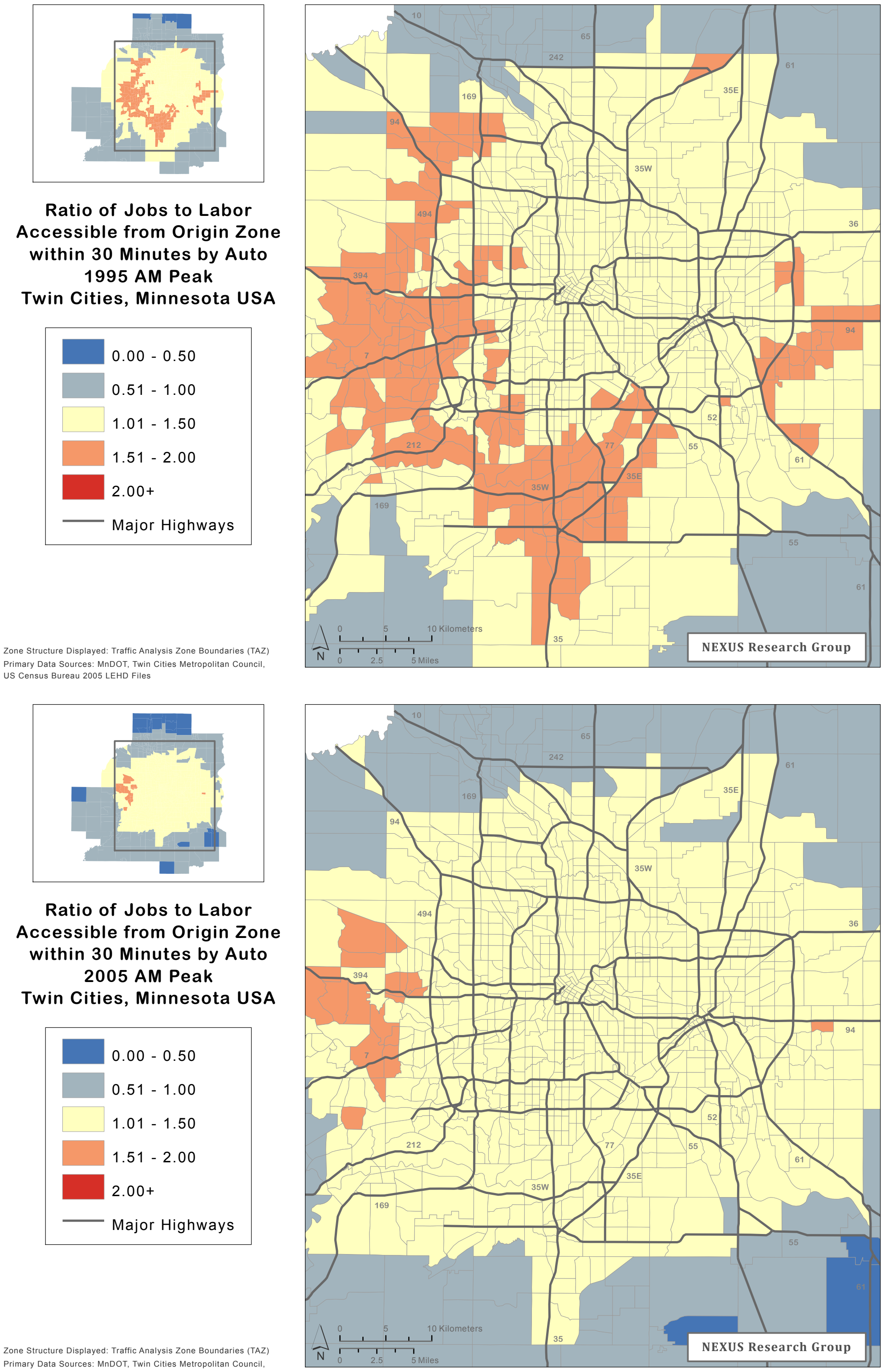


Figure 4.38: Job / worker ratio at 30 minutes.

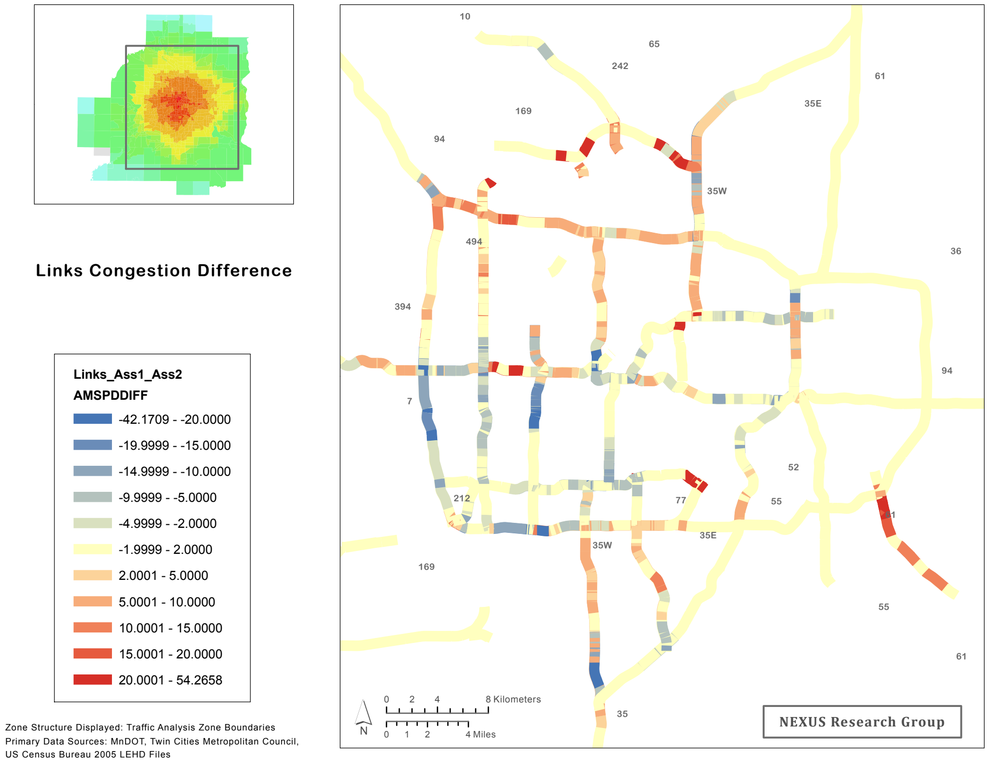


Figure 4.39: Changes in highway speeds in the A.M. peak period.

4.6 Causes of Accessibility Change

What caused the accessibility changes we see? To what extent is it due to changes in the transportation network (either added capacity or changes in congestion level), or due to changes in land use? A series of experiments are conducted to disentangle those changes.

First, as we observe in Figure 4.39, segments colored red indicate faster freeway speeds in 2005 than 1995 and blue indicates slower speeds in 2005. The pattern is mixed. Roads with improvements show significantly faster speeds, while roads under construction or in areas with fast growth (especially in the southwest) show slower speeds.

4.6.1 Change in Land Use

We consider what would have happened had land use not changed. Figure 4.40 shows (a) accessibility to workers in 1995 using 1995 land use and networks (which is the same as shown in Figure 4.17 (top), with a simplified legend), (b) access to workers in 2005 using a 2005 land use and network (which is the same data as shown in Figure 4.17 (bottom)), with (c) a scenario using 1995 land use and 2005 travel times, and a difference comparing the (b) - (c). The greatest increase in accessibility to workers due to land use changes occurs around the I-494/I-694 beltway, and especially in the I-35W corridor south of Minneapolis. The areas where accessibility to workers

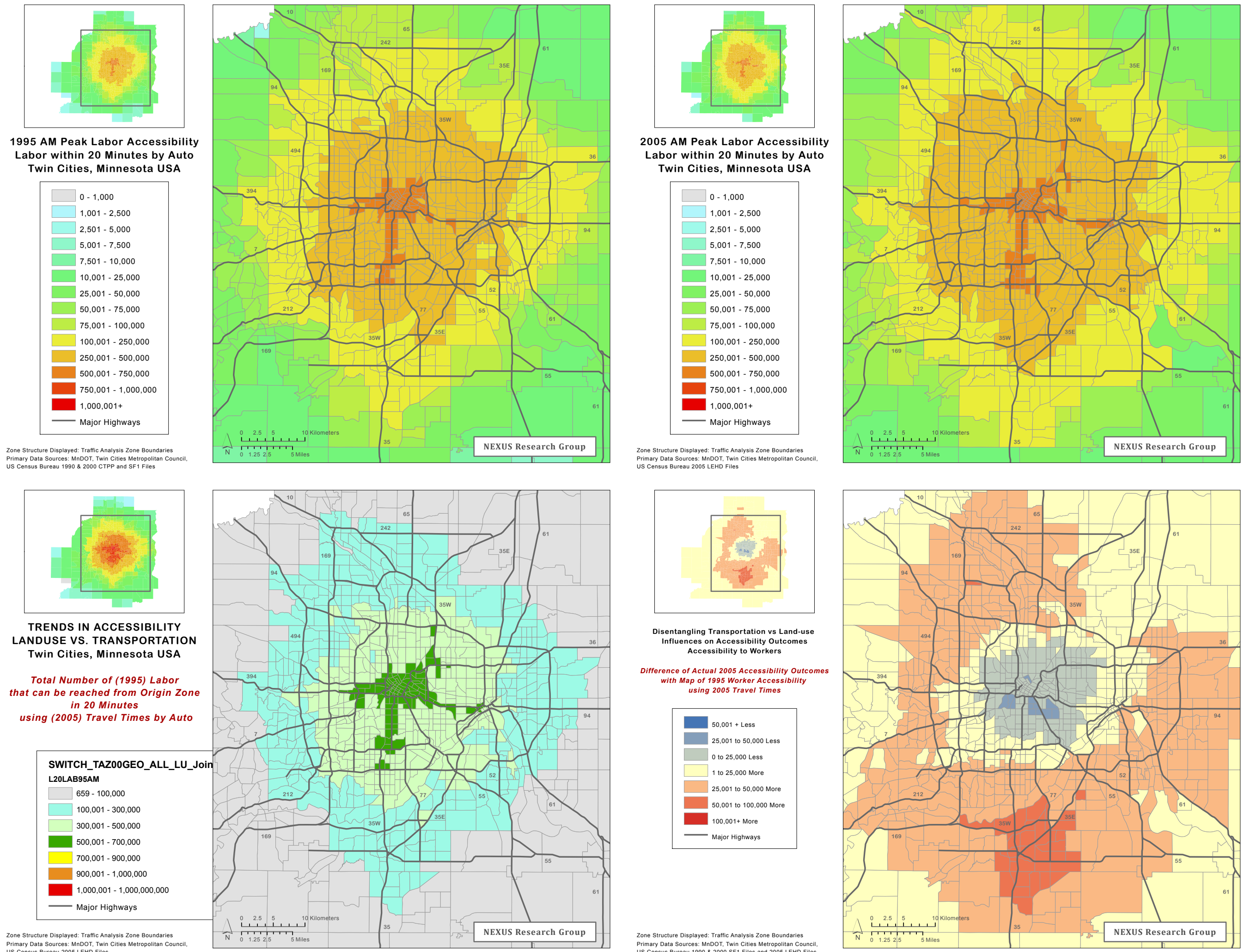


Figure 4.40: Access to workers land use scenarios and differences.

dropped due to land use changes are in the central cities, especially south of I-94 in Minneapolis.

Figure 4.41 shows (a) accessibility to jobs in 1995 using 1995 land use and networks (which is the same as shown in Figure 4.5 (top), with a simplified legend), (b) access to jobs in 2005 using a 2005 land use and network (which is the same data as shown in Figure 4.5 (bottom)), with (c) a scenario using 1995 land use and 2005 travel times, and a difference comparing the (b) - (c). The greatest increase in accessibility to jobs because of land use changes is found in the western suburbs of the Twin Cities, especially the southwest, along the I-494 beltway, while some decreases are shown in certain zones in the eastern part of the metropolitan region.

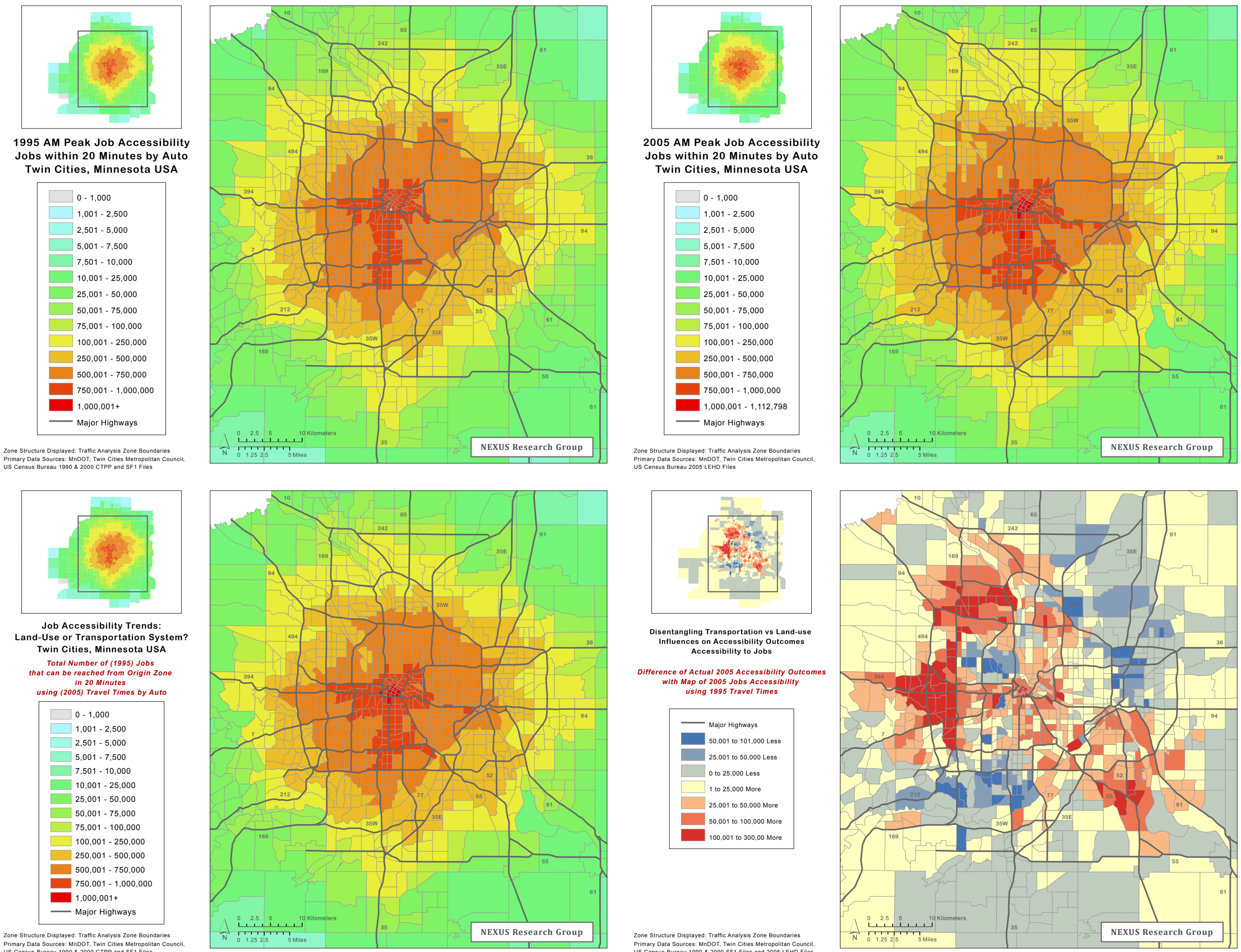


Figure 4.41: Access to jobs land use scenarios and differences.

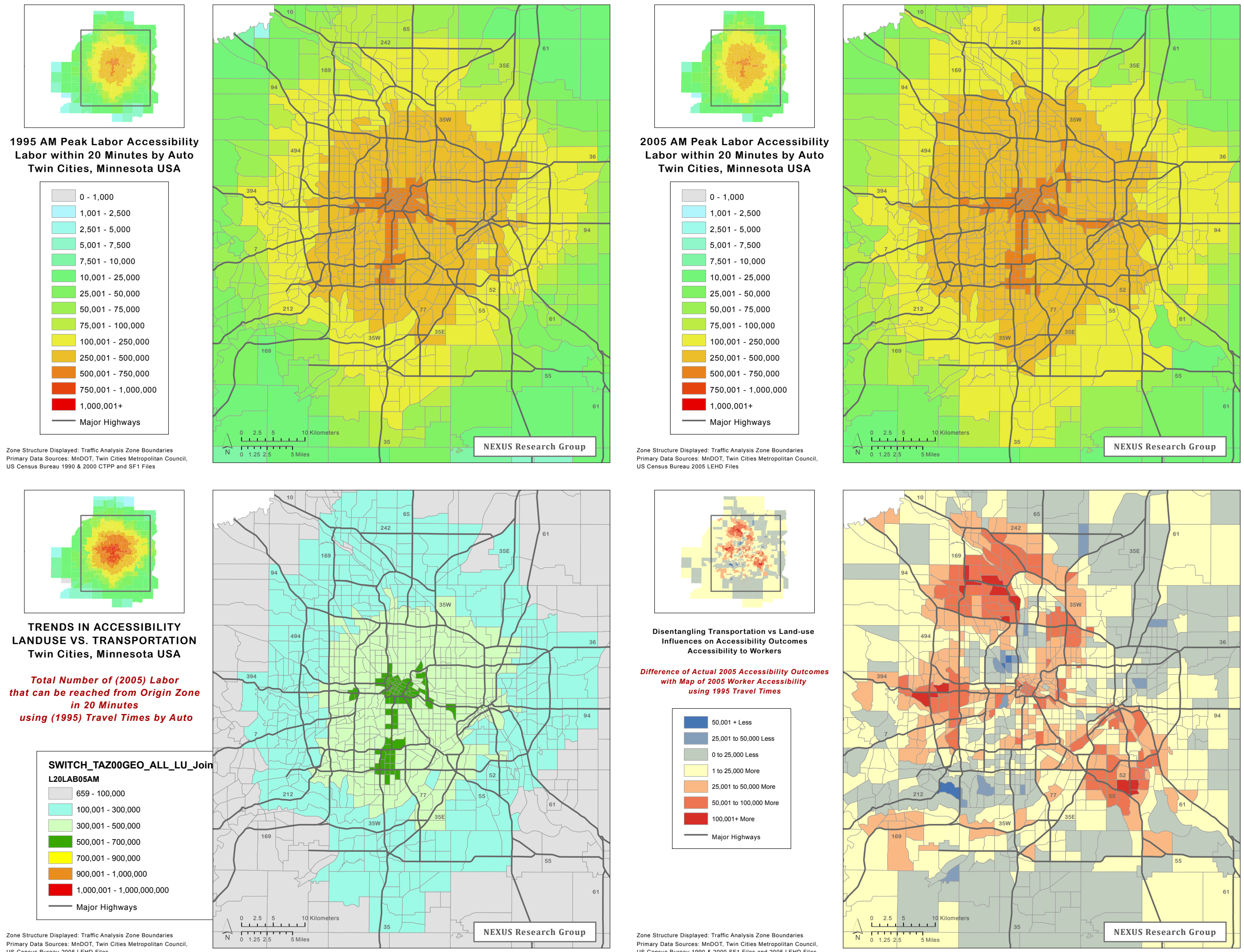


Figure 4.42: Access to workers travel time scenarios and differences.

4.6.2 Change in Networks and Congestion Levels

Now we examine what would have happened to accessibility to workers had the networks not changed. Figure 4.42 repeats (a) accessibility to workers in 1995 using 1995 land use and networks, and (b) access to workers in 2005 using a 2005 land use and network, with (c) a scenario using 2005 land use and 1995 travel times, and a difference comparing the (b) - (c). The greatest increase in accessibility to workers due to travel time changes are in the northwest suburbs, the far west suburbs, and the southeast suburbs. These are due to capacity expansions and new facilities (such as MN 610). In contrast, travel time changes (increasing congestion) affected negatively the southwest suburbs and the northeast suburbs.

Finally we examine what would have happened to accessibility to jobs had the networks not changed. Figure 4.43 repeats (a) accessibility to jobs in 1995 using 1995 land use and networks,

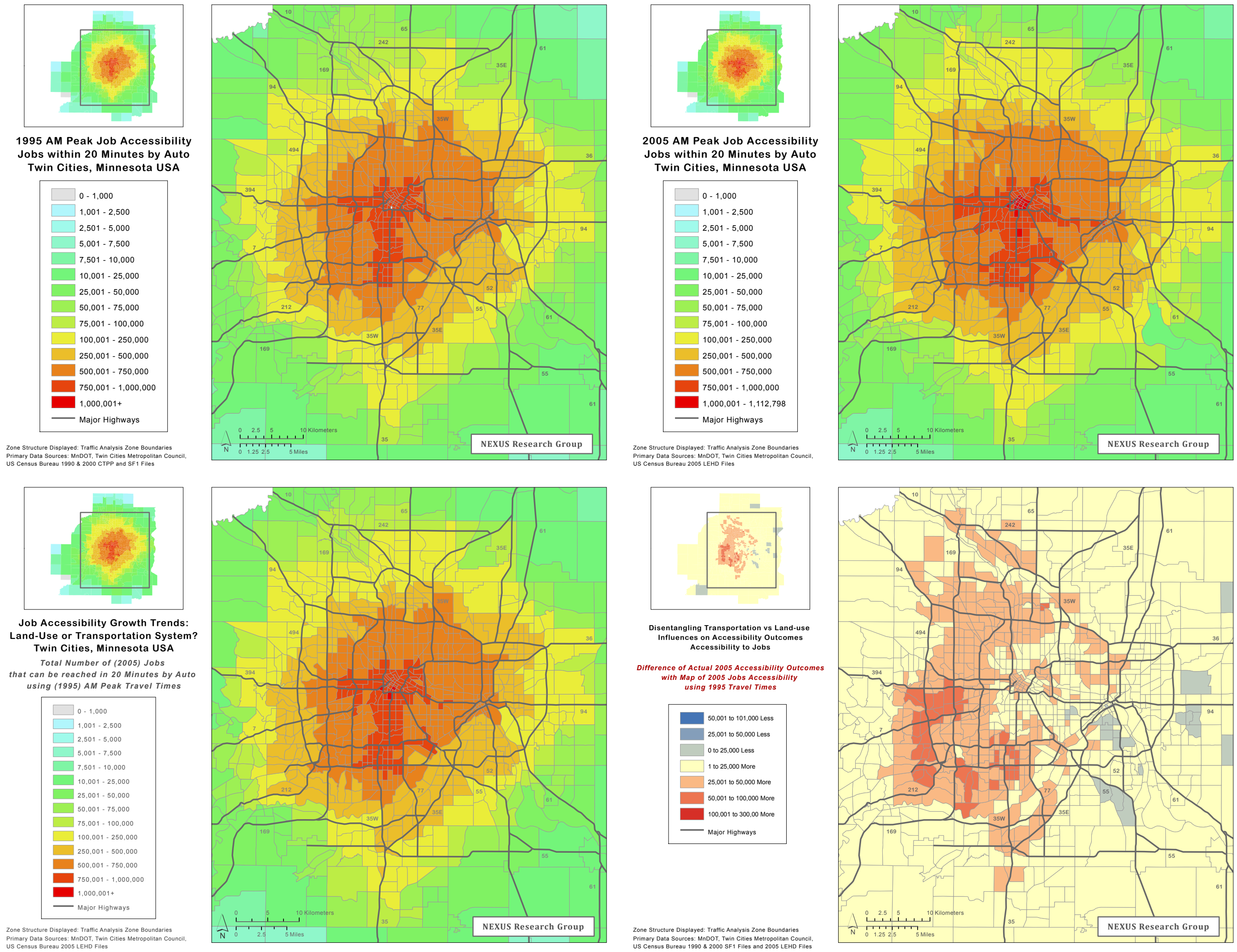


Figure 4.43: Access to jobs travel time scenarios and differences.

and (b) access to jobs in 2005 using a 2005 land use and network, with (c) a scenario using 2005 land use and 1995 travel times, and a difference comparing the (b) - (c). Access to jobs increased due to capacity enhancements in much the same places as accessibility to workers (the northeast, the far west, and the southeast). It declines in the same places as well (the northeast and the southwest), with small increases in the center city.

Chapter 5

Development of Web Module

As part of the project, the research team developed a web-based interface to the Access to Destinations maps displayed in this report using the MapServer program. MapServer is an open source server-based application that converts map data (shape files and the associated databases) into information that can be displayed and queried over the web from the user's browser. We implemented MapServer using the Access to Destinations data, created a custom .map file (which links the data to MapServer, and have hosted it at the following website: http://nexus.umn.edu/mapserver_demos/access/ .

At the above link click initialize. You will then be presented the ability to display and query 8 of the most pertinent Access to Destinations maps. (More maps can be placed online, but only 8 have been done so to date to test for bugs and to limit user cognitive burden under the current interface). These are:

- Access to Jobs by Car in 20 minutes during the A.M. peak period in 2005
- Access to Workers by Car in 20 minutes during the A.M. peak period in 2005
- Access to Jobs by Car in 20 minutes during the A.M. peak period in 1995
- Access to Workers by Car in 20 minutes during the A.M. peak period in 1995
- Access to Jobs by Car in 20 minutes during the A.M. peak period in 2005
- Access to Workers by Car in 20 minutes during the P.M. peak period in 2005
- Access to Jobs by Car in 20 minutes during the P.M. peak period in 2005
- Access to Workers by Car in 20 minutes during the P.M. peak period in 1995
- Access to Jobs by Car in 20 minutes during the P.M. peak period in 1995

The Browse map function allows users to see the map, zoom in and out, and pan across the screen. The Query feature allows users to click on a map and returns the accessibility for the traffic zone representing the point they clicked. The Query Multiple Features allows users to select multiple overlapping maps and returns the accessibility from multiple maps.

Figure 5.1: Screenshot of MapServer introductory screen.

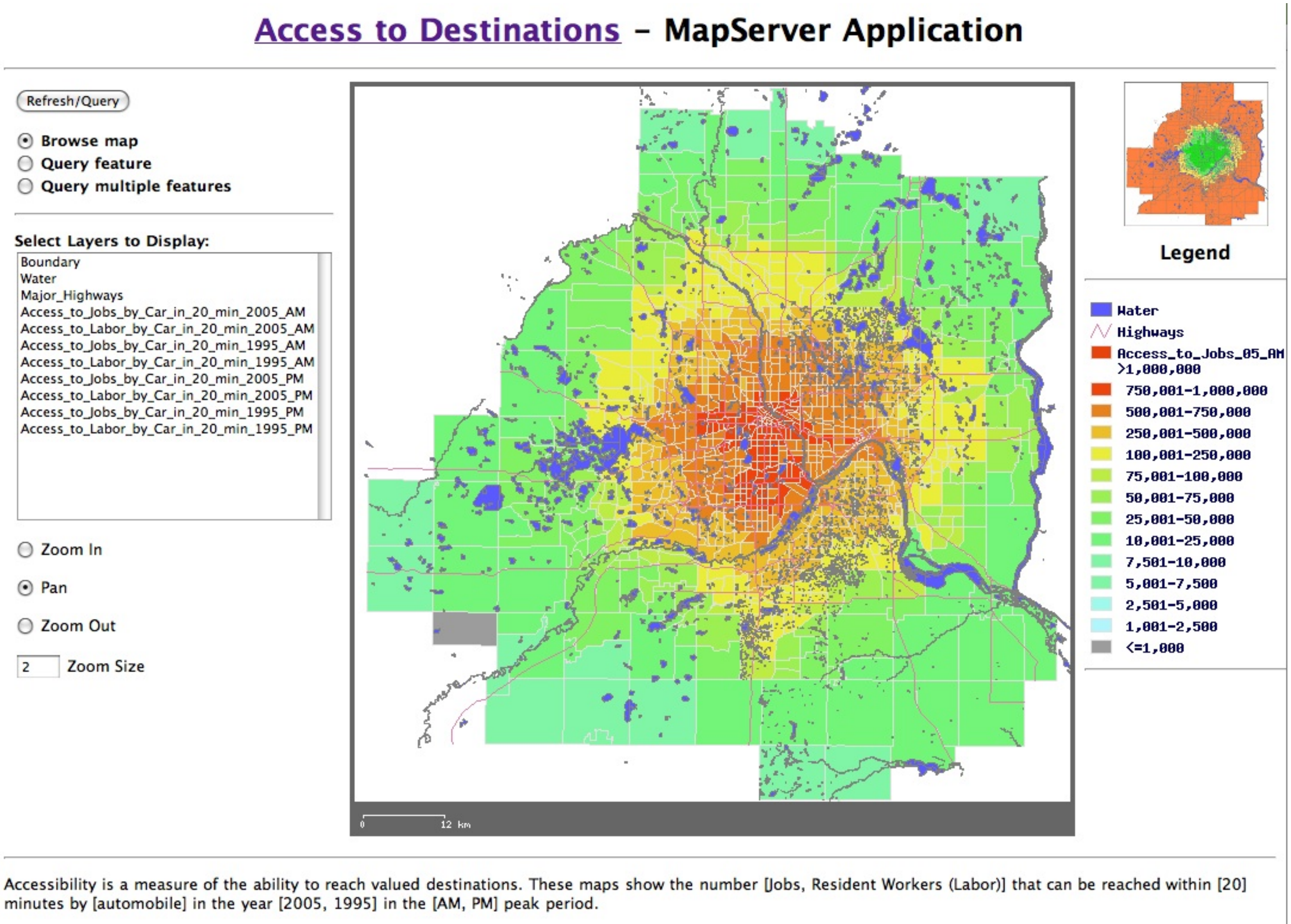


Figure 5.2: Screenshot of MapServer map screen.

Chapter 6

Conclusions

This study describes the process and outcomes resulting from an effort to measure changes in regional accessibility by auto during the period from 1995 to 2005, as part of the *Access to Destinations* study. In contrast to the earlier projects within this study and many other research efforts that make use of accessibility metrics, this project is unique in that it derives time-dependent measures of accessibility that use as inputs travel time estimates based (to the extent possible) on observed link flows, as opposed to modeled flows. These measures are then tracked over time at the zone level to identify the direction and magnitude of accessibility changes.

One key finding of this study is that nearly all parts of the region *increased* became more accessible in absolute terms over the period under study. The greatest growth occurred in faster-growing, suburban parts of the region. This trend was observed when measuring access to both jobs and workers, suggesting that between 1995 and 2005 both households and employers were decentralizing.

Moreover, this process has tended to reduce disparities in levels of accessibility between locations over time, leading to a "flattening" of accessibility across the region. Evidence of broad-based accessibility gains due to urban restructuring is reinforced by the fact that by most standard measures of network performance, traffic congestion was worsening. Locational responses by households and firms, particularly the clustering of activities in certain locations, more than offset the negative impact of the deterioration of network performance. The flattening or convergence of accessibility across locations within the region is corroborated by the additional evidence of job/worker balances improving in most locations, and by the increasing roundness of the standard deviational ellipses describing the distribution of accessibility across locations within the within the region.

Further investigation into the relative causes of these changes reveals that both changes in the location of opportunities and the structure of the transportation network contributed to the increase in accessibility observed throughout the region. Holding either land use or network travel times constant at their 1995 values allows the decomposition of accessibility changes into these two components. Densification of existing centers of activity, primarily around the region's beltway, led to increased job access in many such locations. Likewise, some limited network improvements (i.e. TH 169, 212 and 610) improved job access near the locations where they took place. The southwestern part of the region was a major beneficiary of these improvements. Only modest declines in accessibility as a result of land use and network changes were observed, and these tended to be limited to a handful of central city locations.

The results of this study help to demonstrate the superiority of accessibility as a measure of transportation performance. Accessibility measures provide a more complete picture of system performance by synthesizing the effects of changes to both transportation networks and the destinations they serve. In the absence of information on the location of opportunities, one may have concluded that most locations within the Twin Cities became less accessible over the period from 1995 to 2005. Our results have led largely to the opposite conclusion. Within cities, it is access to desired destinations that households value, and hence it is important to select measures that reflect how well these needs are being served. Our findings make a strong case for the inclusion of accessibility as a critical component of performance evaluation for transportation engineers and planners.

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Appendices for this report may be obtained by contacting the Center for Transportation Studies Library Services at ctslib@umn.edu.