Accessibility Futures

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Abstract

This study uses accessibility as a performance measure to evaluate a matrix of future land use and network scenarios for planning purposes. Previous research has established the coevolution of transportation and land use, demonstrated the dependence of accessibility on both, and made the case for the use of accessibility measures as a planning tool. This study builds off of these findings by demonstrating the use of accessibility-based performance measures on the Twin Cities Metropolitan Area. This choice of performance measure also allows for transit and highway networks to be compared side-by-side. A zone to zone travel time matrix was computed using SUE assignment with travel time feedback to trip distribution. A database of schedules was used on the transit networks to assign transit routes. This travel time data was joined with the land use data from each scenario to obtain the employment, population, and labor accessibility from each TAZ within specified time ranges. Tables of person-weighed accessibility were computed for 20 minutes with zone population as the weight for employment accessibility and zone employment as the weight for population and labor accessibility. The person-weighted accessibility results were then used to evaluate the planning scenarios. The results show that centralized population and employment produce the highest accessibility across all networks.

Keywords: Accessibility, Planning, Minnesota

1 Introduction

Transportation and land use are inter-dependent. The relationship between these two has been used to explain the growth patterns of cities, and continues to be influential in the decisions by businesses and individuals of where to locate in a city. Understanding this relationship is also important for planning future growth. Land use plans and transportation plans are typically conducted independent of each other, but the two need to be compatible if the goals of both are to be realized.

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Accessibility is defined as the ability of people to reach the destinations to meet their needs and satisfy their wants, and has been long used in transportation planning (Hansen, 1959). It is a function of both land use and the transportation network and can also be thought of as a measure of the efficiency of a city. This study develops a set of land use and transportation network scenarios, and evaluates accessibility for each scenario.

Transportation planning has traditionally focused on improving mobility and reliability measures of congestion across a metropolitan area. While policy based on these criteria can improve access to jobs or labor, they can have unintended effects as well. First, mobility improvements, when this means improving the connectivity of outlying areas, tend to shape land use by encouraging decentralization. Second, focusing efforts only on reducing congestion is an automobile-centric policy that ignores and often reduces accessibility for people using other modes. Finally, congestion may not matter much, as Levinson and Marion (2010) show that accessibility increased across the Twin Cities Metropolitan Area from 1995 to 2005 even as traffic congestion worsened by most network measures. Levinson and Marion (2010) have made a strong case for the use of accessibility as a performance measure in land use and transportation planning and we will demonstrate its use here by evaluating a series of future scenarios.

The use of scenarios is widespread in planning practice, a comprehensive review and meta-analysis can be found in (Bartholomew and Ewing, 2009). Scenarios are not forecasts (though forecasts may be scenarios). In planning, scenarios have often been used in transportation and in land use models to consider alternative policies, and what might their implications be on outcomes like vehicle miles traveled or air pollution. In this study we consider how different patterns affect accessibility.

The next section describes the 6 land use scenarios, 5 highway networks, and 1 transit network considered in this study. Land use data is developed for each transportation analysis zone (TAZ). A travel time matrix (TAZ to TAZ) is developed for each network and joined with land use data to find the total employment, labor, or population reachable for each time threshold. After that is a methodology on accessibility, followed by a results section analyzing a quantitative result: person-weighted accessibility calculated at 30 minute thresholds. We conclude by considering the implications for planning in the Twin Cities and the potential for future research.

2 Data

This study analyzes the accessibility of 36 different scenarios, representing each combination of 6 land use scenarios and 6 networks. They are as follows.

2.1 Land Use

2.1.1 2010 Land Use

The 2010 land use (scenario LE) is the existing land use (jobs, households, population by TAZ) in the Twin Cities metropolitan area as of 2010. This is used as a baseline scenario. When paired with the 2010 highway network (N1), this reproduces the existing accessibility. For all other networks, the 2010 land use is used to show the result of network modifications if the region saw no significant growth in the period 2010-2030. Maps of population and employment density by TAZ in 2010 are shown in Figure 1. The highest population densities (over 6000 per km^2) are in the neighborhoods just south of downtown Minneapolis. Downtown Saint Paul shows somewhat greater population density compared with the surrounding area. Otherwise, population density is relatively uniform (1500 to 6000 persons per km^2) across the central cities and inner suburbs (Richfield, east Bloomington, West St. Paul, South St. Paul, Columbia Heights, St. Anthony Village, Brooklyn Center, Brooklyn Park, Crystal, New Hope, Robbinsdale, Hopkins, and St. Louis Park). Population density in the remaining suburbs is generally less than 1500 per km^2. Employment in the region is highly concentrated in downtown Minneapolis, with a much smaller concentration in downtown St. Paul. There are significant employment concentrations at many freeway to freeway intersections, although most of these employment nodes are on the southwest side of the Metro area.

2.1.2 2030 Land Use

The 2030 land use scenario (scenario LF) is the land use predicted by the Metropolitan Council in its comprehensive plan. The bulk of the growth is expected to occur in outlying areas at low densities. Despite this, there are still some interesting changes. Maps showing the change from 2010 are given in Figure 2 .

The population in both downtowns is expected to increase significantly, which amounts to a prediction that the recent condo boom will continue. South of downtown Minneapolis, the neighborhoods west of I-35W are predicted to grow, while a decline is projected for virtually all neighborhoods between I-35W and Hiawatha Avenue. The areas of highest growth are in Dayton, Hugo, Rosemount, Lakeville, Elko New Market, and unincorporated areas of Carver County. The 2030 employment map is almost the same as the 2010 map in terms of the geographic distribution of employment. Significant increases are projected in downtown Minneapolis and along I-494/694, specifically in Edina, Eden Prairie, Plymouth, and Maple Grove. There is also expected to be significant growth in Shakopee, Apple Valley, Lake Elmo, and Dayton although these are likely to be service sector jobs associated with population growth in those areas.

2.1.3 Centralized Population and Employment

The centralized population and employment scenario (LCC) uses the same metropolitan totals of population, employment and labor as the Metropolitan Council's 2030 Comprehensive Plan, but concentrates all of the growth (beyond 2010) inside the I-494/694 Beltway. All population and employment outside the Beltway is held constant at 2010 values. This scenario can be used to evaluate the effectiveness of a growth strategy that funnels investment into developed areas.

A map of the centralized population and employment growth can be found in Figure 3. These maps show the increase in population or employment, respectively, from 2010 to 2030, broken down by TAZ. This scenario can be used to evaluate the effectiveness of a growth strategy that funnels investment into developed areas.

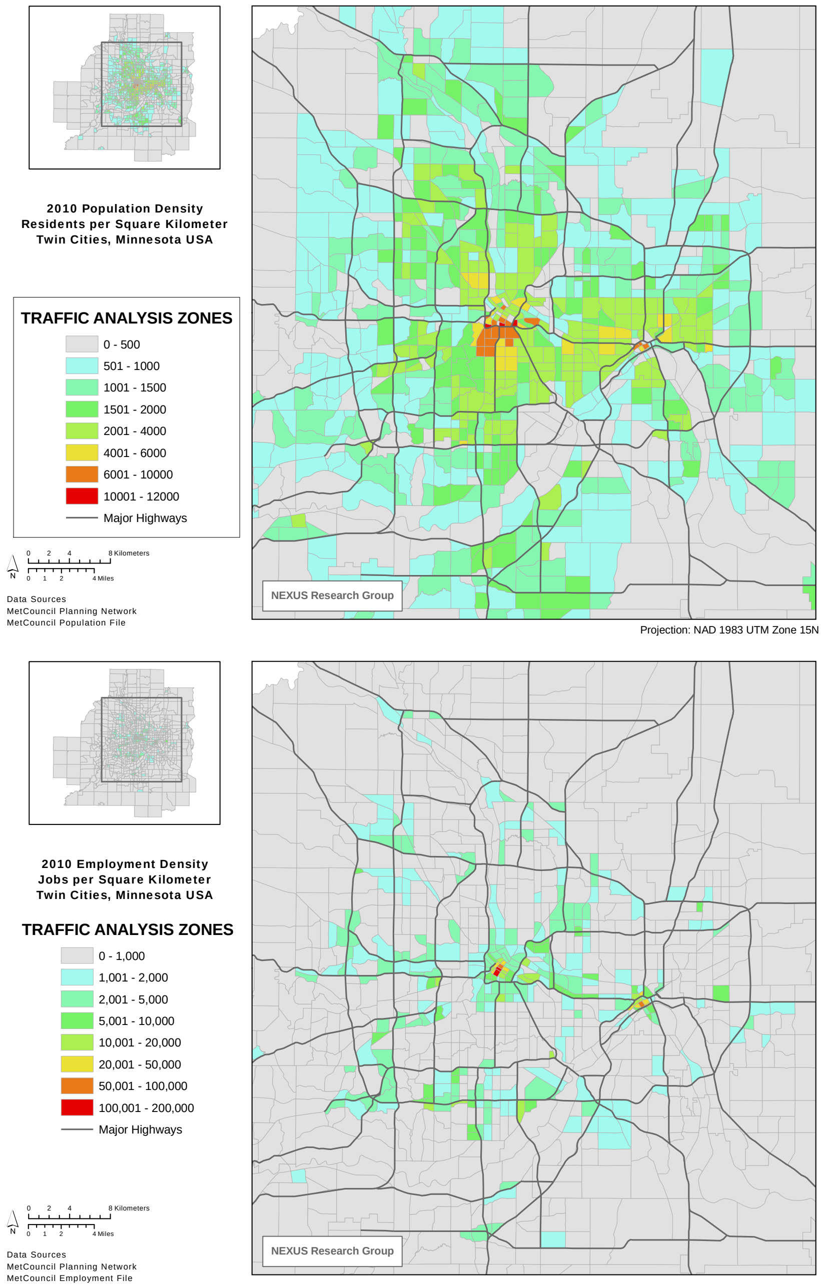
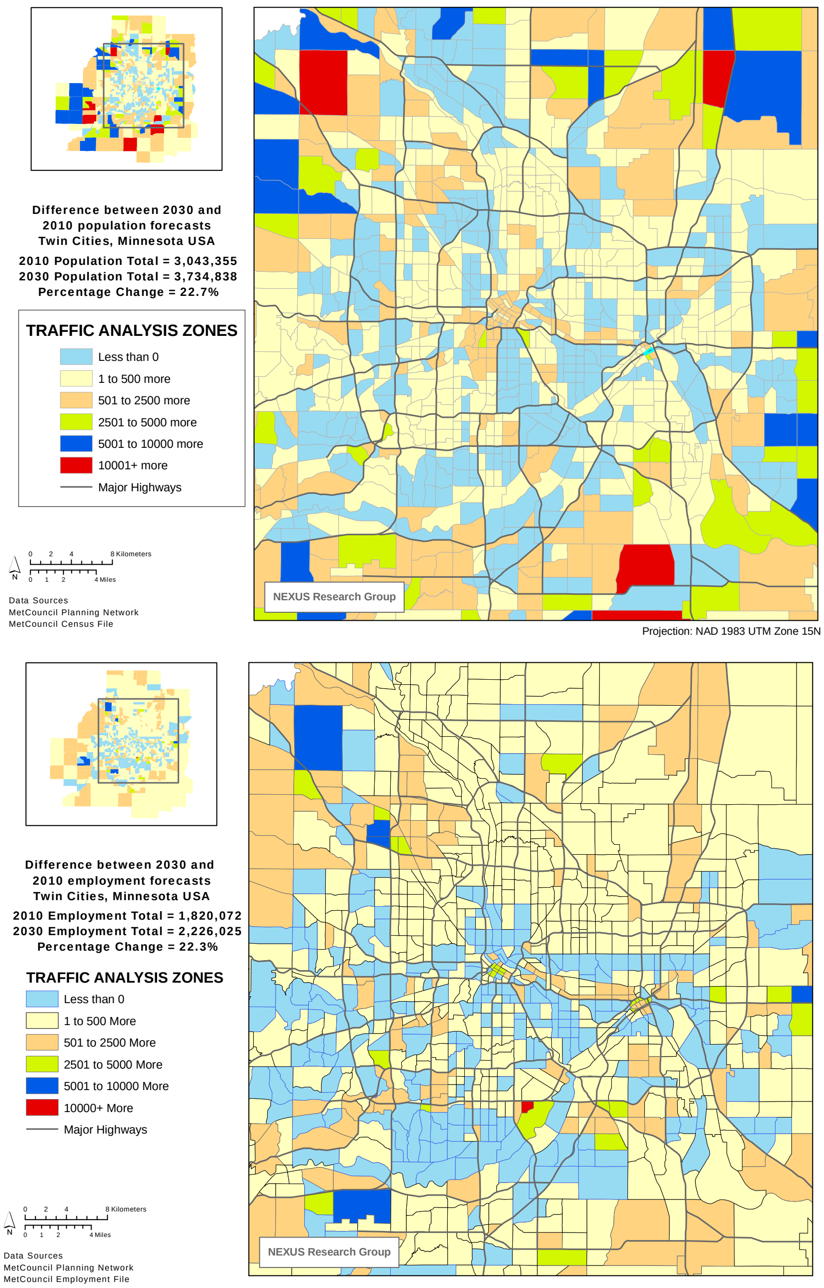


Figure 1: 2010 Population and Employment Density

Figure 2: Population and EmploymentChange 2010-2030



2.1.4 Centralized Population, Decentralized Employment

The centralized population, decentralized employment case (LCD) is meant to evaluate the impact on accessibility if population growth occurred only within the I-494/694 Beltway and job growth only occurred outside it.

2.1.5 Decentralized Population, Centralized Employment

The decentralized population, centralized employment scenario (LDC) is the reverse of the previous section. All population growth occurs outside the I-494/694 Beltway and all job growth occurs inside it.

2.1.6 Decentralized Population and Employment

The decentralized population and employment scenario (LDD) shifts all population and employment growth outside the I-494/694 Beltway. This scenario can be used to evaluate the changes in accessibility that would result from a full dispersion scenario (i.e. no effort is made to increase population/employment in already developed areas). A map of the decentralized population and employment growth is shown in Figure 4.

2.2 Highway Networks

2.2.1 Freeflow

The freeflow network (N0) has no congestion whatsoever and is used to evaluate what the accessibility would be under ideal conditions or if there were some technological advance resulting in greatly increased effective capacity (e.g. autonomous vehicles), or some policy that eliminated congestion.

Effectively, there are only 4 land use scenarios for this network. The two mixed centralized/decentralized scenarios have the same geographic distribution of accessibility as the appropriate all centralized/decentralized scenario for this network because congestion is absent. However, the weights for person-weighted accessibility change, so the numbers are different for all six land use scenarios. For all other networks, the location of labor affects access to employment (and vice versa) because it alters congestion patterns.

2.2.2 2010 Highway Network

This scenario represents the existing highway network as of 2010 (N1) . The scenario with 2010 Land Use is the existing condition, while all other scenarios with this network show what would happen in 2030 without any network improvements.

2.2.3 2030 Highway Network

This case (N2) includes all network improvements envisioned by the Metropolitan Council in their Comprehensive Plan. Most of the changes are new roads or expansions outside the Beltway, but there are a few freeway expansions planned inside the Beltway: I-494 near Woodbury, I-35E north of downtown Saint Paul, MN-36 in Maplewood, and I-94 near the

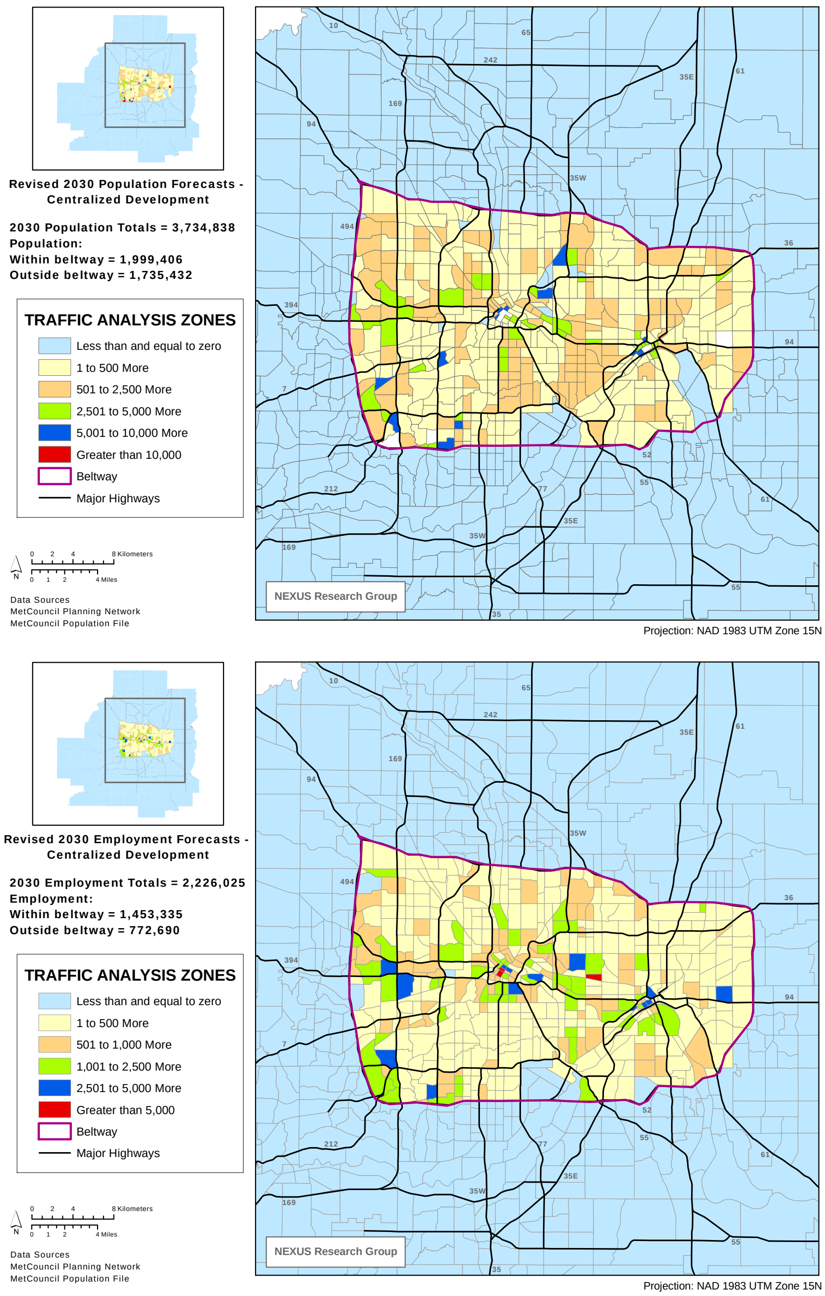


Figure 3: Centralized Population and Employment Growth

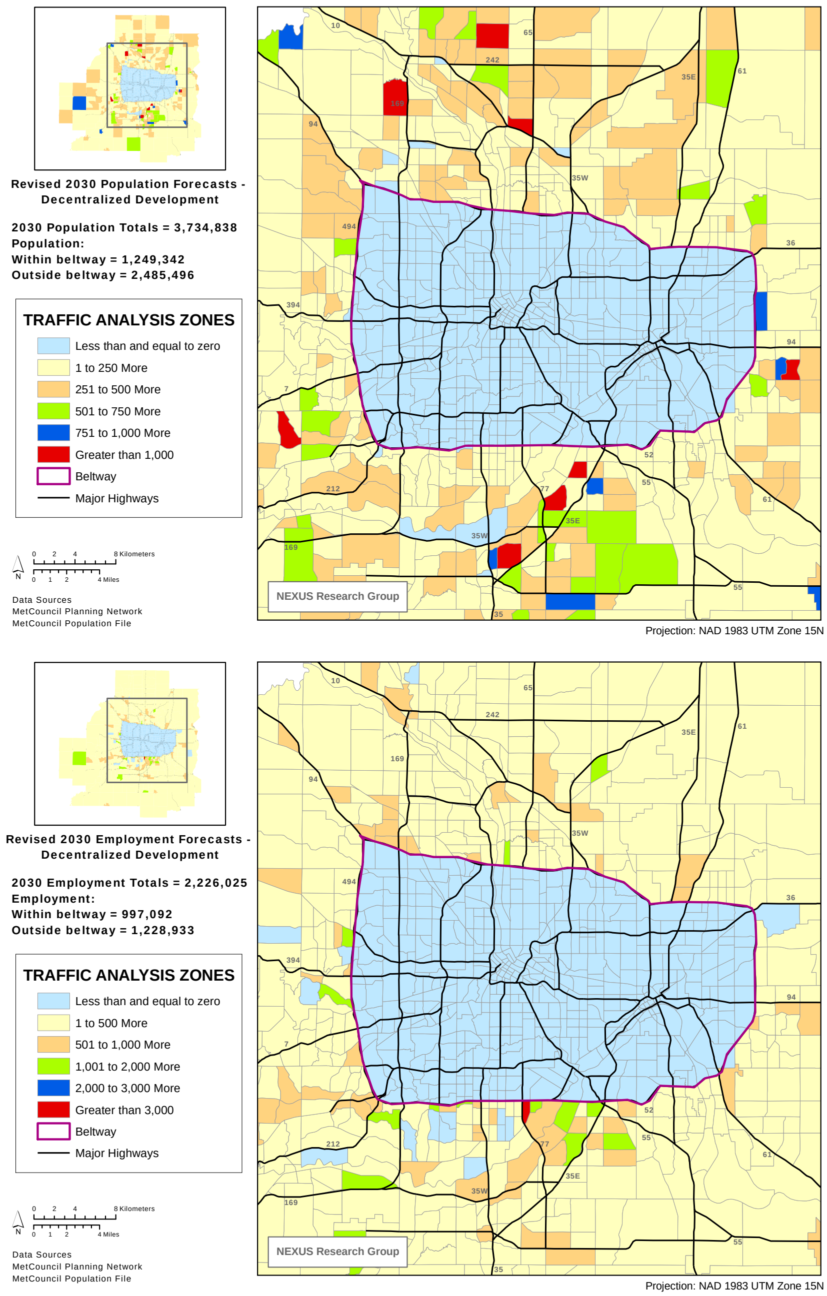


Figure 4: Decentralized Population and Employment Growth

University of Minnesota campus. A map with these changes highlighted is shown in Figure 5. The scenario with 2030 Land Use shows the 2030 accessibility if all growth and network improvements occur according to the Comprehensive Plan.

2.2.4 Diamond Lane Network

This scenario (N4) represents the 2030 highway network with the addition of HOT lanes. As of 2010, HOT lanes exist on I-394 and I-35W south of downtown Minneapolis. This network would extend HOT lanes to the rest of the freeway network on or inside the Beltway. As such, this network will be similar to the freeflow network because freeflow travel is possible on most freeway links (assuming the HOT lanes are regulated to maintain freeflow speed). The cost of tolls is not included in the accessibility measure here.

2.2.5 Congestion Pricing

This scenario (N5) represents the 2030 highway network with congestion pricing implemented. This was modeled by assigning users to network paths in order to achieve a system optimal solution. A true system optimal would be difficult to achieve, but this modeled scenario could be implemented by using dynamic pricing to move users away from heavily congested links. The toll that users pay in this scenario was assumed to be in terms of travel time (i.e. the volume delay function (link performance function), which is normally the average cost of travel, was converted to the marginal cost function, so the difference represents the additional congestion cost travelers impose on others. As a consequence the accessibility measured from this scenario is not the simply the time cost travelers pay, but a composite of time cost plus marginal cost (as if the toll were converted to travel time). This follows the methodology developed and applied by (Anderson and Mohring, 1997).

2.3 Transit Networks

2.3.1 2030 Transit Network

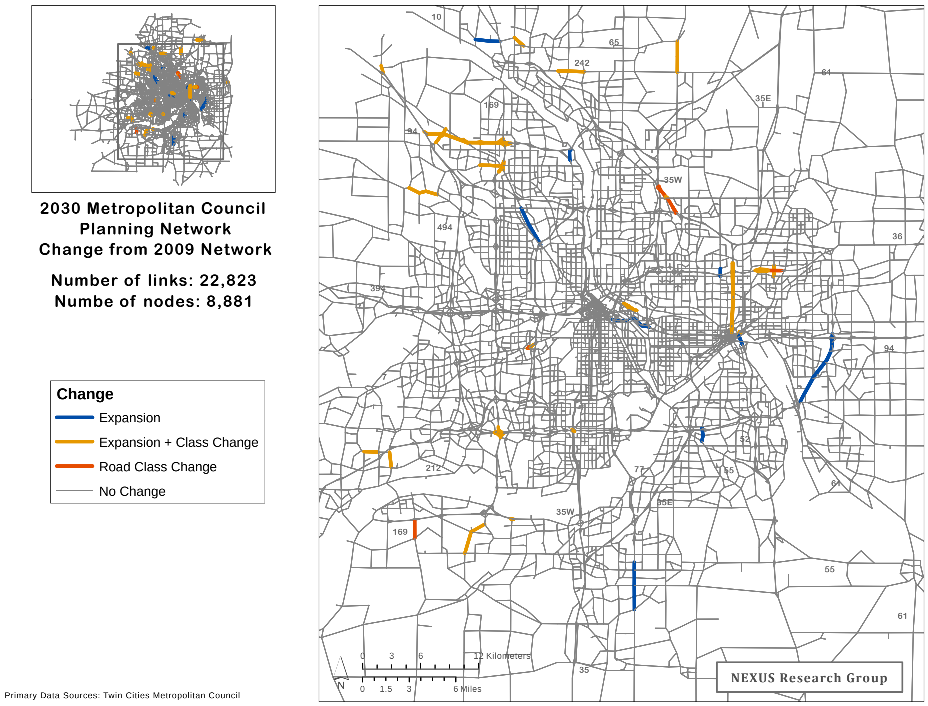
This scenario considers accessibility by public transit (T1). The transit network is the anticipated 2030 network according to the Metropolitan Council. It includes the Bottineau, Rush Line, and Cedar Avenue transitways (as BRT), the Central Corridor and Southwest light rails, and the Red Rock commuter rail east of Saint Paul. In addition to these, there are also a number of planned bus routes that are not part of a transitway or feeders into a rail line. A map of all the transit networks is shown in Figure 6

3 Methodology

3.1 Alternative Land Use Scenarios

Centralized and Decentralized population and employment were allocated based on the 2010 land use and the 2030 Comprehensive Plan forecast. The procedure for centralized population is as follows. Zones within the beltline which experienced negative growth from 2010 to 2030 were reverted to 2010 population. Zones within beltline with zero or positive growth were

Figure 5: 2030 Highway Network



left at 2030 population. Zones outside the beltline with positive growth were reverted to 2010 population, while zones with negative or zero growth were left at 2030 population. The first iteration allocated positive growth from outside the beltline to zones with negative growth inside the beltline by the formula:

$$B_{i+1} = B_i + \frac{B_{2010}}{\sum B_{2010} + \bar{B}_{2010}} * [\sum \bar{B}_{2030} - \sum \bar{B}_{2010}] \tag{1}$$

where:

B = TAZs inside the beltline

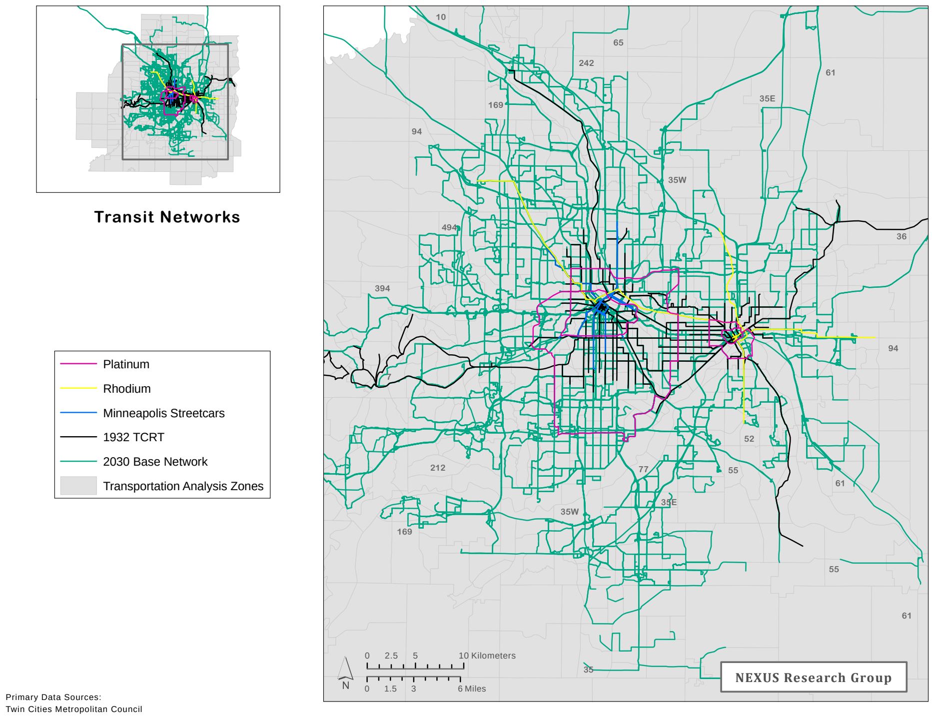
$\bar{B}$ = TAZs outside the beltline

The next steps assigned the remaining difference between the total 2030 Comprehensive Plan population and the total population at the end of the last step, first to zones inside the beltline with zero growth, then to zones inside the beltline with positive growth, and then to all zones inside the beltline using the above formula (with the remaining unallocated population replacing the term in brackets). Iterations of this were run until the remaining population stabilized. At this point, the remainder was divided evenly among the zones with the 10 lowest (nonzero) populations.

3.2 Highway Travel Time Calculations

The highway scenarios, with the exceptions of the freeflow and diamond lane networks, were run in the SAND model developed as part of a previous project and summarized below.

Figure 6: Transit Networks



4 Travel Demand Model

The highway travel demand model used in this project is called SAND - Simulator and Analyst of Network Design. The new 2009 Metropolitan Council planning network that serves as a base network has been conflated to real network geometry. This network includes 22,477 links, 8,619 nodes, 35 external stations, and 1,236 transportation analysis zones (TAZ) for demand analysis. Links are divided into 15 categories according to their functional classes and link capacities, including AM peak, PM peak and off-peak capacities, are estimated by Metropolitan Council. The travel demand model has been calibrated against the real traffic measured by the loop detectors, and then used to predict the morning peak hour traffic. The model also estimates the morning peak hour factor using the detector data and expands peak hour traffic to AADT. Given that the public transit ridership only accounts for 3% of daily travel in the Twin Cities area, SAND directly estimates vehicle trips as a simplification of the traditional four-step process. For the same reason, the freight traffic is not explicitly modeled in this study. Instead, we inflate the passenger car traffic to account for the missing freight traffic.

4.0.1 Calibration

The travel demand model is calibrated against traffic data provided by loop detector stations. MnDOT maintains about a thousand traffic count stations on freeways throughout the Twin Cities Metro area. Volume and speed is measured every 30 seconds and the data are documented at MnDOT traffic data server. We randomly picked 10% of the full set of detector stations, removed malfunctioning detectors, and matched 73 out of the remaining stations with the planning network. As shown in Figure 7, this set of detector stations represents a good sample of the entire Twin Cities freeway system, including I-35W, I-35E, I-94, I-494, I-694, I-394, TH 36, TH 52, TH 62, TH 77, TH 100, TH 169, TH 212 and TH 280. The morning peak hour traffic rate is estimated by averaging the traffic volume from 7:00 am to 9:00 am during the weekdays of the first full week, April 2010. The peak hour rate, which is used to expand peak hour cost to daily cost, is estimated by comparing the peak hour rate and daily volume of observed at these stations.

The target of calibration is to minimize the different between the morning peak hour volumes estimated by the model and the actual morning peak hour volume observed on the selected set of links. As trip generation models have been calibrated separately and the peak hour factor has been directly estimated from the traffic data, the only parameter to be adjusted in calibration is the trip distribution friction factor θ. The parameter is calibrated by using a brute force search technique. The friction factor that provides the best fit is $0.151 \cdot min^{-1}$, resulting in an overall 0.25% error between the average volumes that predicted by the model and the average real traffic count given by the detectors. The R^2, estimated by regressing forecast peak hour volumes on observed volume for selected stations is 0.94. The root mean square error (RMSE) is 28%.

4.0.2 Trip Generation

Trip generation module estimates the number of personal vehicle trips that originate from (production) or are destined to (attraction) each traffic analysis zone. The traffic production and attraction models are separately estimated by regressing the 2005 composite vehicle trip rates by TAZ, which is provided by Metropolitan Council, on a set of zonal characteristics variables. The model that provided the best goodness-of-fit is adopted. The following explanatory variables turn out to be significantly correlated with the dependent variable:

- Population
- Retail Employment
- Non-retail employment
- Residential density
- Shortest distance from centroid zone to either downtown Minneapolis or St. Paul (estimated within ArcGIS)
- Shortest previous distance squared

4.0.3 Trip Distribution

Trip distribution allocates trips generated in one zone to destination zones in the study area. In our study all trips are treated equally and one aggregate Origin-Destination matrix is generated through this process since we do not distinguish trips by purpose. This study adopts

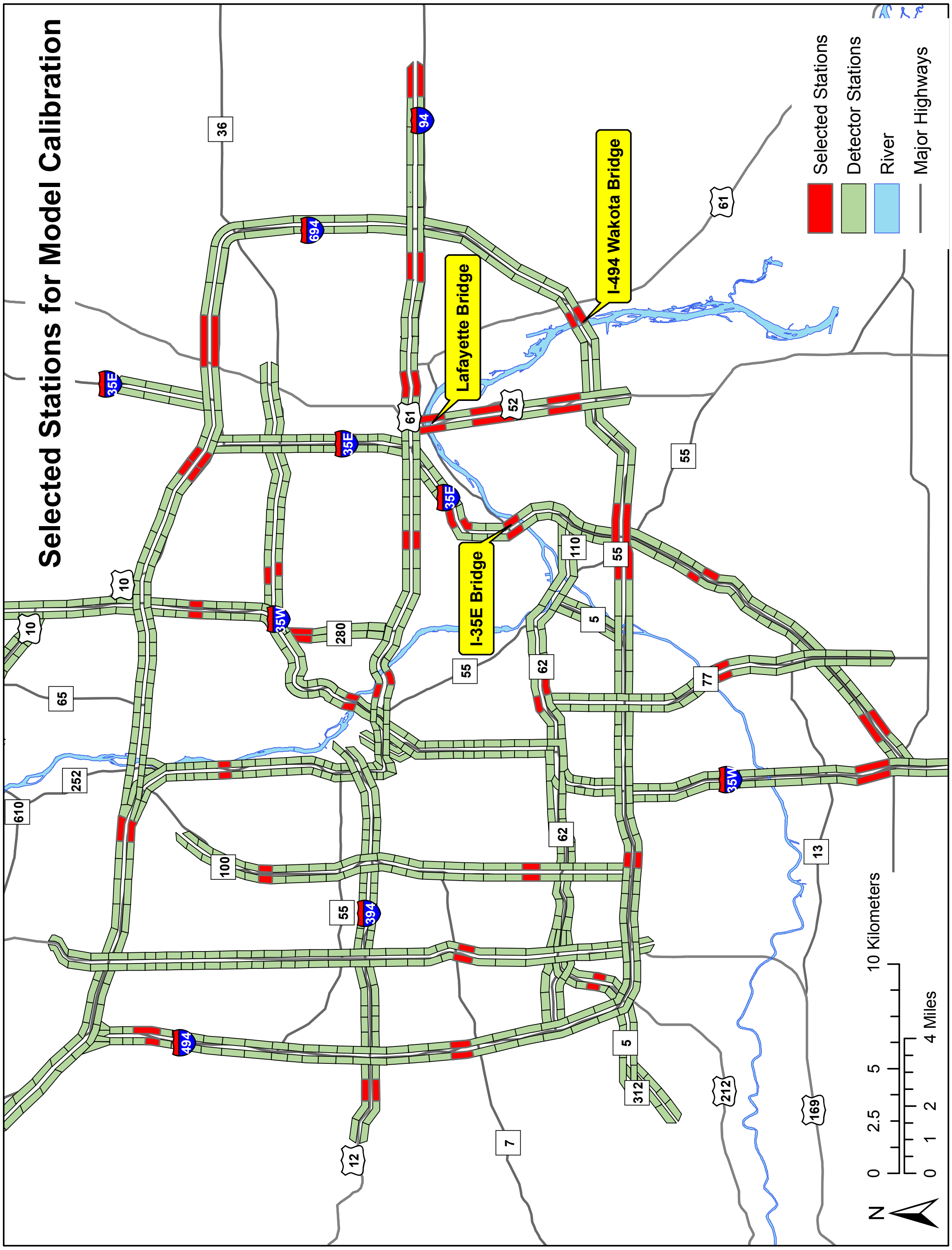


Figure 7: Selected 73 stations for model calibration

a doubly constrained gravity-based trip distribution model. The gravity model assumes that the travel demand between two locations is positively associated with the amount of activity at each location but declines with increasing impedance between them, which is modeled by a the negative exponential function of the travel cost here. The friction factor θ is a parameter to be calibrated in the model. It is an inverse function of travel time, which captures where people prefer longer or shorter trips.

4.0.4 Route Assignment

Traffic assignment determines the actual route that will be used by travelers between each Origin-Destination pair and the number of vehicle trips can be expected on each network link. The predicted network traffic pattern depends on the assumption about route choice preferences among travelers. SAND employs a Stochastic User Equilibrium (SUE) model which is originally introduced by Daganzo and Sheffi (1977), and assumes that travelers choose the route with minimum perceived travel time. Dial's algorithm (Dial, 1971) is used to perform network loading and the Method of Successive Average (MSA) is used to find the SUE link flow. The Bureau of Public Road (BPR) link performance function is adopted to derive the congested link travel time as a function of link flow rate and capacity. Following Leurent (1997), a scaling coefficient of 0.2 is used in the discrete choice module. The convergence for MSA is defined by a maximal allowable link flow change below a threshold of 100 vehicles.

For the congestion pricing network, the link function was transformed from an average cost to a marginal cost

$$MC = \frac{\delta(Q * AC)}{\delta Q} \tag{2}$$

This increases the costs for congested links by the amount of delay a driver is imposing on other vehicles, thereby moving travelers to less congested links (in the short run) and to changing trip destinations in the long run. These long run feedbacks are included in the model, which iterates between trip distribution and route assignment.

The model returns population and employment accessibility (cumulative opportunities) for each TAZ at the six time thresholds (10, 20, 30, 40, 50, 60 minutes). The freeflow travel times were computed by running travel time skims in TransCAD. Additionally, the diamond lane network was created from the 2030 network model run by replacing the link speeds on freeway segments with HOT lanes with freeflow speeds. This assumes high occupancy toll facilities are operating at freeflow speeds.

4.1 Transit Travel Time Calculations

The transit scenarios were run using an SQL database following the procedure in (Krizek et al., 2007) . This code took schedules, transfers, and stop data as inputs. The data for the current (2010) network was supplied by Metro Transit in this format.

New routes were first drawn in ArcMap 9.3 from the Metropolitan Council's 2030 plan. Stops were added in new areas, but only at a frequency of two per TAZ considering the scale of this analysis. Using Network Analyst tools, nearby stops were associated with each route and the distance between stops along the route was measured. Each new route was classified as an urban local, limited stop, suburban local, express, LRT, or commuter rail and schedule times were calculated based on the average speed (from end to end, which includes stop dwell times) for current routes in the same class. Schedule headways were given by the Metropolitan Council. None of the new routes have timed transfers; for example, if a route has a 15 minute headway then it starts trips at 6:00, 6:15, 6:30 and so on. Transfers between routes were calculated assuming no greater than a 200m walk radius.

Once the schedules, transfers, and stops had been produced for the new routes, this data was loaded into the database. For each stop, the code calculates what census blocks can be reached with a maximum of one transfer and saves the lowest travel time to each block. When the code has finished running, a file of block to block travel times is exported. The block to block files were converted to TAZ to TAZ files and dissolved to obtain the lowest travel time for each TAZ pair. Using ArcMap, another TAZ to TAZ matrix was created of walk times, assuming an average speed of 5 km/h. The walk time matrix takes the centroid to centroid distance between TAZs, multiplied by 1.2 (a typical circuity value found by Parthasarathi and Levinson (2011)). These two TAZ to TAZ matrices were combined, and the lowest time was taken for each pair. This leads to a low level of accessibility in outlying areas, despite having no transit service, as individuals could walk between zones.

4.2 Accessibility Calculation

The cumulative opportunity accessibility measure is traditionally defined as:

$$A_{i,T} = \sum_{j=1}^{J} O_j D(C_{ij}) \tag{3}$$

where:

$A_{i,T}$ = cumulative opportunities from a zone (i) to the considered type of opportunities (j) reachable in time T.

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

$D(C_{ij}) = 1$ 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 10 minutes to 60 minutes .

The cumulative opportunity measures are combined to develop a complete time-weighted accessibility measure used in this report uses a different impedance function, defined in (Levinson and Kumar, 1994) as:

$$A_i, tw = \sum_{T=10}^{60} (A_{i,T} - A_{i,T-10}) \cdot e^{\beta * T} \tag{4}$$

where:

β = -0.08

T = time threshold for cumulative accessibility

This measure weighs the cumulative accessibility at 10 minute intervals from 10 to 60 minutes. The result, a weighted employment accessibility for each TAZ, is weighed by zone population as described above.

An overall person-weighted accessibility A_{pw} is calculated for employment by multiplying the cumulative accessibility by zone at the time threshold by a weight W_i (e.g. the zone population) and dividing the product by the sum of the weights. The same calculation was performed for population and labor, but with zone employment as the weight.

$$A_{pw,T} = \frac{\sum_{i=1}^{I} A_{i,T} \cdot W_i}{\sum_{i=1}^{I} W_i)} \tag{5}$$

Similarly a composite time-weighted, person-weighted accessibility is

$$A_{pw,tw} = \frac{\sum_{i=1}^{I} A_i \cdot W_i}{\sum_{i=1}^{I} W_i)} \tag{6}$$

5 Results

Figure 8 shows person-weighted accessibility at 20 minutes for jobs. Looking across the different land use patterns, the highest person-weighed accessibility to jobs and to labor in almost all scenarios comes with centralized employment and population (LCC). The second highest is usually with centralized population and decentralized employment (LCD). However for labor accessibility, and the Met Council anticipated 2030 network (N2), decentralized population and centralized employment (LDC) slightly outperforms LCC and LCD. In all cases LCC has higher accessibility than fully decentralized growth (LDD).

In general centralizing population and decentralizing (LCD) employment produces more access to jobs than decentralizing population and centralizing employment (LDC), consistent with the suggestion of (Levinson, 1998). This scenario will also produce shorter commute times. It also usually produces more access to labor.

Compared to the forecast scenario, LCC produces about 20 to 25 percent more accessibility, depending on the network configuration.

Figure 9 shows the time-weighted accessibility measure. Although the numerical values are different, the overall trends are essentially the same. Centralized population and employment produces the highest accessibility, followed by centralized population and decentralized employment. The decentralized population, centralized employment scenario performs better than the 2030 comprehensive plan on the freeflow, diamond lane, and 2030 transit networks, but falls behind on the 2010, 2030, and congestion pricing networks.

Comparing networks, the freeflow network (N0) has the highest accessibility, followed by the Diamond Lane network (N4) (which has freeflow times on the freeway system inside the Beltway) (excluding the cost of tolls). The freeflow network (N0) has about 20 percent more accessibility than forecast network (N2). So if some technology could bring about freeflow travel, we would expect accessibility to be about 20 percent higher in peak. It is even greater for shorter time thresholds (i.e. the number of jobs that can be reached in 20 minutes increases more than 20 percent). The Diamond Lane network, which has freeflow times on freeways has about two-thirds as much gain as N0 compared to N2.

The anticipated 2030 network (N2) generally bests the existing 2010 network (N1) except when there is centralized population and centralized employment (LCC), but the two are very similar. Remember while the trip generation is the same across networks, the trip distribution is not, and depends on congestion levels. So adding to capacity in some areas will re-distribute demand and reroute traffic and thus shift congestion. While there may be a net reduction in congestion (this is not guaranteed), the change in congestion will make some places more accessible and others less. The model nets this out and solves for the equilibrium. It turns out adding capacity in some places reduces accessibility to others. The added capacity in general adds about about 2 percent to 20 minute accessibility to jobs and 1 percent to 30 minute regional accessibility to jobs.

The congestion pricing scenario is only slightly better than N2. The reason is the the "tolls" are paid in terms of travel time in this scenario, so the costs are embedded, which differs from the assumption in the Diamond Lane network. That said, it provides about a 1 to 2 percent increase in (generalized time plus money) accessibility over the base, after considering tolls. This model accounts for the spatial benefits of tolling in terms of reallocating traffic to better routes, and some redistribution of traffic to different destinations, but does not fully account for time of day shifts, as the trip generation (by time of day) is fixed.

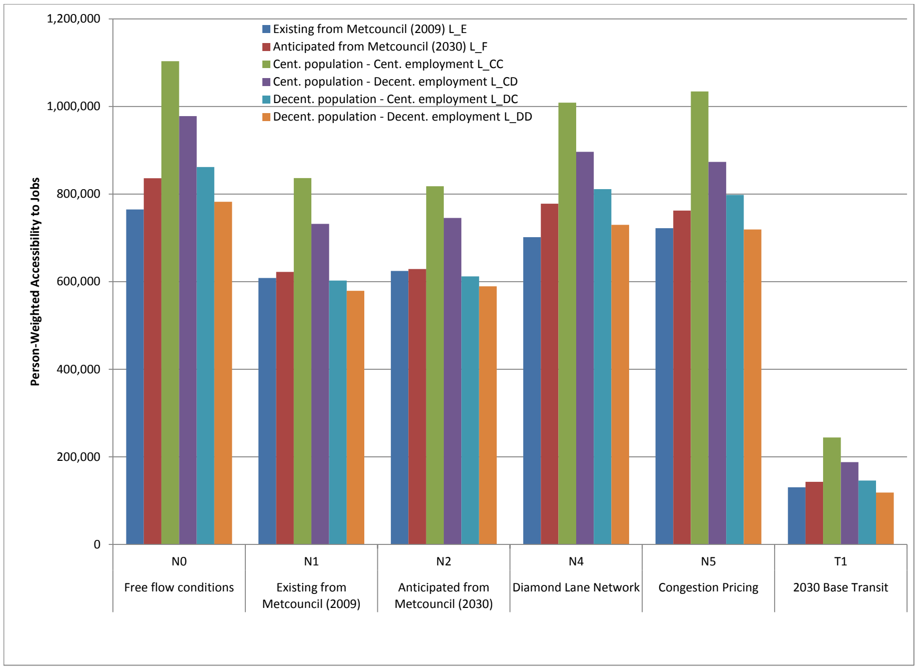
Transit accessibility is about twice as high in the centralized LCC vs decentralized LDD scenarios, indicating transit works significantly better at connecting people to jobs at higher densities.

Figures 10 shows the ratio of highway to transit accessibility by zone at 20 minutes. The highway network, transit network, and land use in these figures are all from the Metropolitan Council's 2030 Comprehensive Plan. At 20 minutes, there are some zones with a ratio near 1, while many outlying areas have ratios well over 100. Transit fares relatively well in this comparison in Minneapolis, Saint Paul, and some of the inner-ring suburbs, but does poorly outside of the I-494/694 Beltway. The highest ratios are found in outer-ring suburbs and exurban areas, which is to be expected.

6 Conclusion

This study uses accessibility measures to compare a set of planning scenarios for the Twin Cities Metropolitan Area. At first glance, it would be easy to pick out the combination of land use and network with the highest accessibility and select that as the planning goal. Although this combination, centralized population and employment on a freeflow network, might be ideal, it is likely not cost-effective or feasible under current technologies. Trying to achieve this combination would mean working against both the trends of increasing congestion (due to population growth) and decentralization of population and employment. Instead, the best use of these results are the comparisons that can be made.

First, a change in land use is more effective than the anticipated changes in the network, though moving to a freeflow network (through technological change or through pricing) would have significant time accessibility improvements (20 percent) though clearly at some monetary cost. Levinson and Marion (2010) came to the conclusion that network changes have a more local effect while land use changes have a regional effect. That is confirmed here, and one of the strongest arguments in favor of this conclusion is a comparison between the



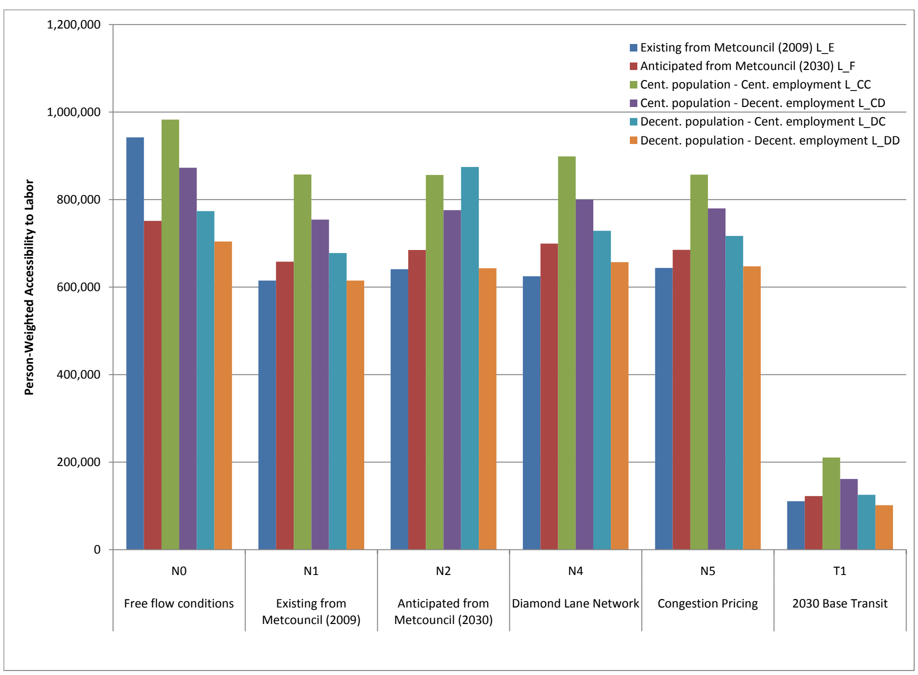


Figure 8: Person-Weighted Accessibility to Jobs and Labor: 20 Minutes

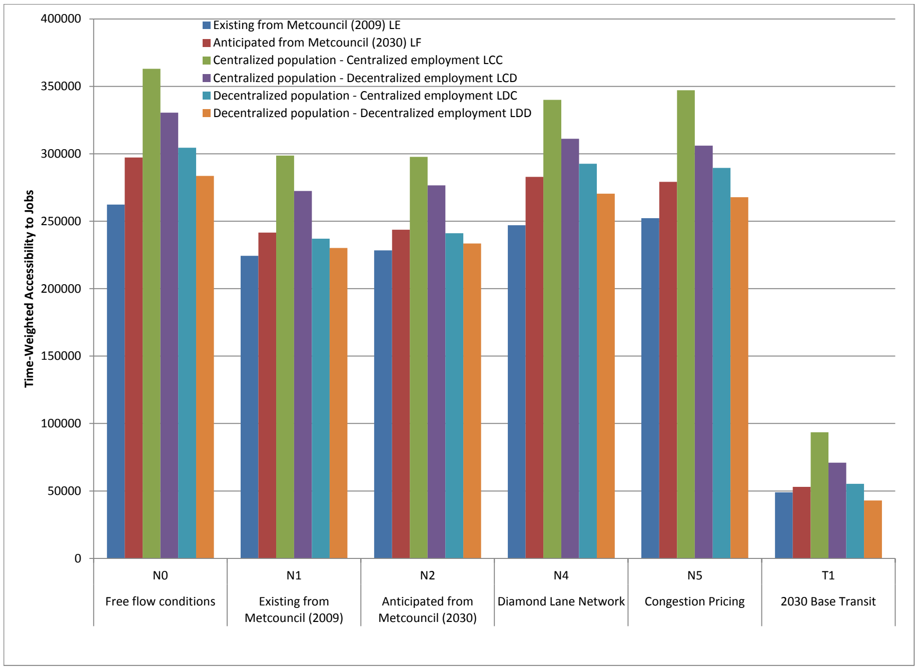


Figure 9: Time-Weighted Accessibility to Jobs

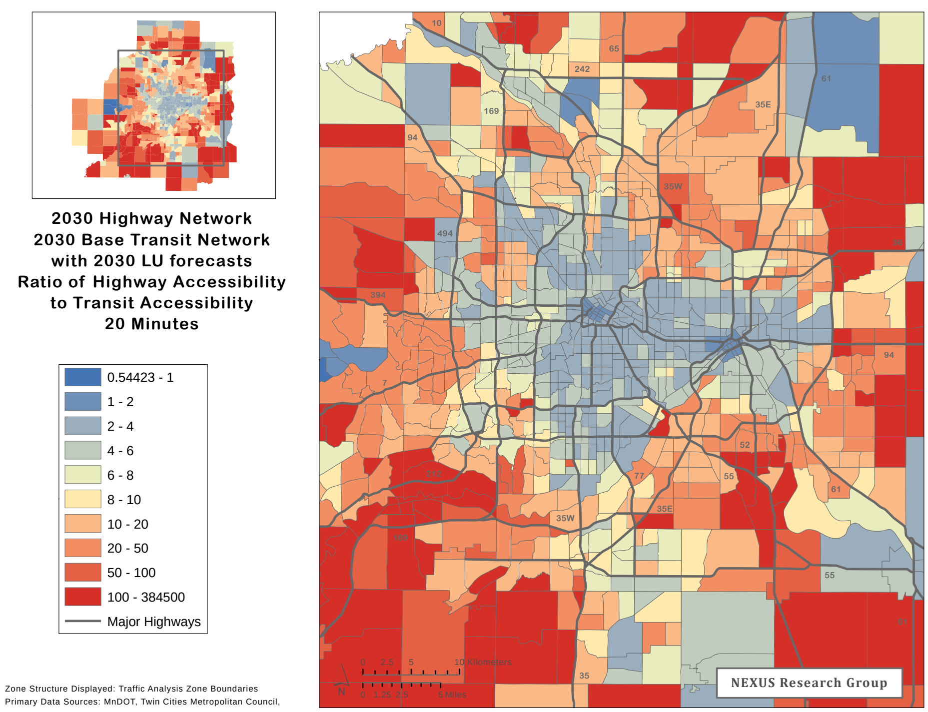


Figure 10: Ratio of Highway to Transit Accessibility: 20 and 30 Minutes

centralized population decentralized employment and the decentralized population centralized employment scenarios. The Twin Cities have highway and transit networks that were designed to serve a decentralized population commuting to centralized employment, and yet reversing this land use trend has higher accessibility, as it can make use of under-utilized capacity in the off-peak direction. This is not so surprising on the highway networks, as they work just as well for reverse commutes, but is interesting to see for the transit network as they are still designed to bring commuters into downtown.

The results of this study show that accessibility measures are a viable tool for comparing planning scenarios. With a selection of possible scenarios as broad as this one, it would be difficult to select one as the best choice to implement without knowing more about the cost and feasibility of each option. If the trend of decentralized development is too difficult to reverse, an investment in congestion pricing or HOT lanes might be best. On the other hand, decentralized development renders the transit system ineffective and reduces the effectiveness of the highway system in connecting people to jobs. A concentrated effort for higher densities and infill development in the central cities would benefit accessibility the most, and this study shows that increasing the centralization of population is more important than centralizing additional employment. A good use for this type of analysis would be to prioritize investments and land use strategies based on how "accessibility-effective" they are, or how much accessibility per unit dollar of investment. In determining final investment and planning strategies, the value of accessibility to jobs or labor needs to be traded off against other values.

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