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Nice Stations: An Exploration of Nice Ride Bike Share Accessibility and Station Choice

Final Report

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16. Abstract (Limit: 250 words)

Little is known about how people integrate bike share trip segments into their daily travel. In this study, we evaluate how people navigate from place to place using the Nice Ride Minnesota bike share system in the Minneapolis-St. Paul metropolitan area. We measure changes in job accessibility due to the addition of Nice Ride stations and develop a theoretical model for bike share station choice. The mapped results suggest that Nice Ride provides the strongest job accessibility improvement at the 30-minute threshold in a band just beyond the central business district where walking would not be feasible.

We then model people's choice of origin station to evaluate their sensitivity to time spent walking, distance, and a set of station amenity and neighborhood control variables. As expected, people prefer to use stations that do not require deviating from the shortest path to reach a station. For commuters, each additional minute of walking decreases a station's chance of being chosen, regardless of the overall trip length. Commuters also chose stations closer to parks. Conversely, users making non-work trips are sensitive to the *ratio* of walking to biking time (with a preference for time spent biking). Stations in neighborhoods with lower crime rates were more likely to be chosen for all trip purposes. The results from this study are important for planners who need a better understanding of bike share user behavior to design or optimize their system. The findings also provide a strong foundation for future research about bike share system modeling.

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Executive Summary

Introduction

Research Objective

This study considers how people integrate bike-share into their daily travel by:

- Mapping improvements in job accessibility provided by Nice Ride bike-share stations
- Developing a theoretical model of how people choose bike-share stations at the start of their trip
- Analyzing trip records from about 500 Nice Ride Minnesota bike-share users in the 2012 season
- Empirically testing the effects of directness, total travel distance, and relative walking and biking time on users' choice of origin station
- Control for environment and personal factors, such as proximity to parks, neighborhood income and crime statistics, and trip purpose

Background and Theory

Bike-share trips, like public transit trips, are composed of three primary segments:

- Station access walking segment
- On-bicycle segment(s) between stations
- Station egress walking segment

Research about transit suggests that people value time spent in each of these segments differently, and station area amenities affect the station's utility [2, 5, 3]. Pedestrian environment factors increased utility for some stations by about 21 to 33%, shifting the balance of how many people would choose the station with a longer walking path (versus a subway transfer) based on travel time advantage alone.

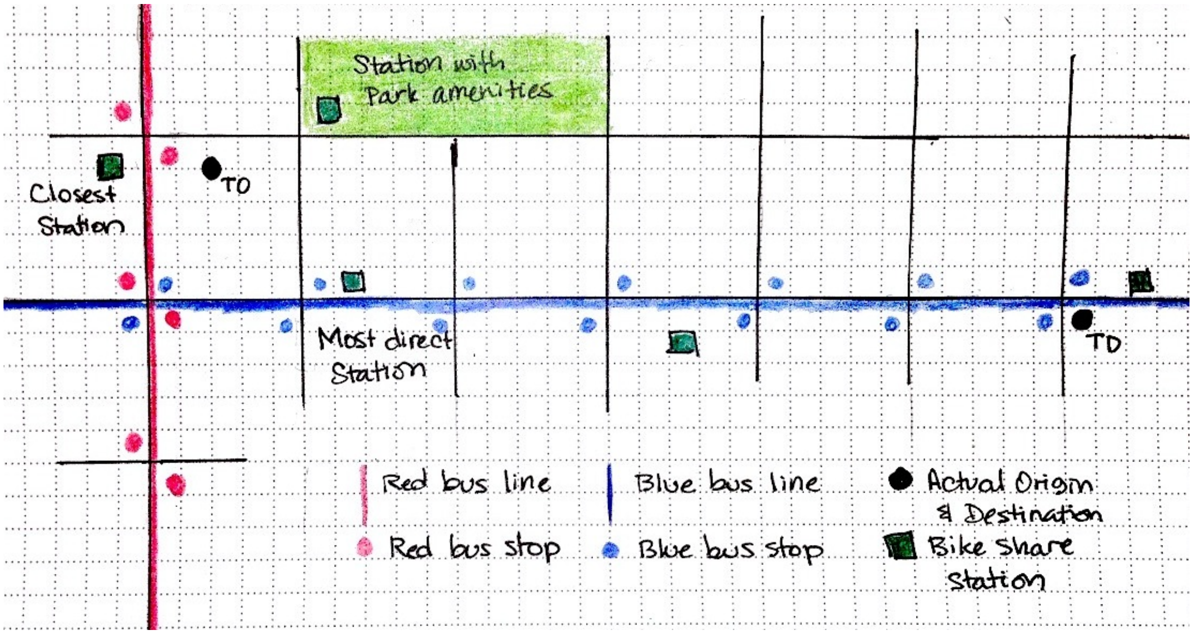

Figure 1: Flexible Routing Options of Bike-Share Versus Transit Users

Bike-share users have even more station options than transit users because stations are not linked to fixed routes. Figure 1 shows how the flexible routing options of bike-share enables the user to choose a station that meets their preferences.

Figure 2 show the relative value of retrieving a bicycle from the closest station versus walking farther in the direction of travel. An individual traveling from TO (true origin) to TD (true destination) will experience equal travel time retrieving a bicycle from anywhere along the kite-shaped boundary that corresponds with their speed. Depending on station placement, the individual may reduce their travel time by walking in the opposite direction from their destination to pick up a bicycle.

Methodology

The data used in this study come from three main sources:

- Distribution of jobs at the census block level from the US Census Bureau
- Distribution of stations at the end of the 2011 season from Nice Ride Minnesota
- An online survey about bike-share trips administered by Nice Ride Minnesota to all monthly and annual subscribers in May-June 2012

We geocoded the stations used, route, purpose, and walking access/egress segments for 506 trips. The choice set was defined as the five closest stations to the respondent's true origin.

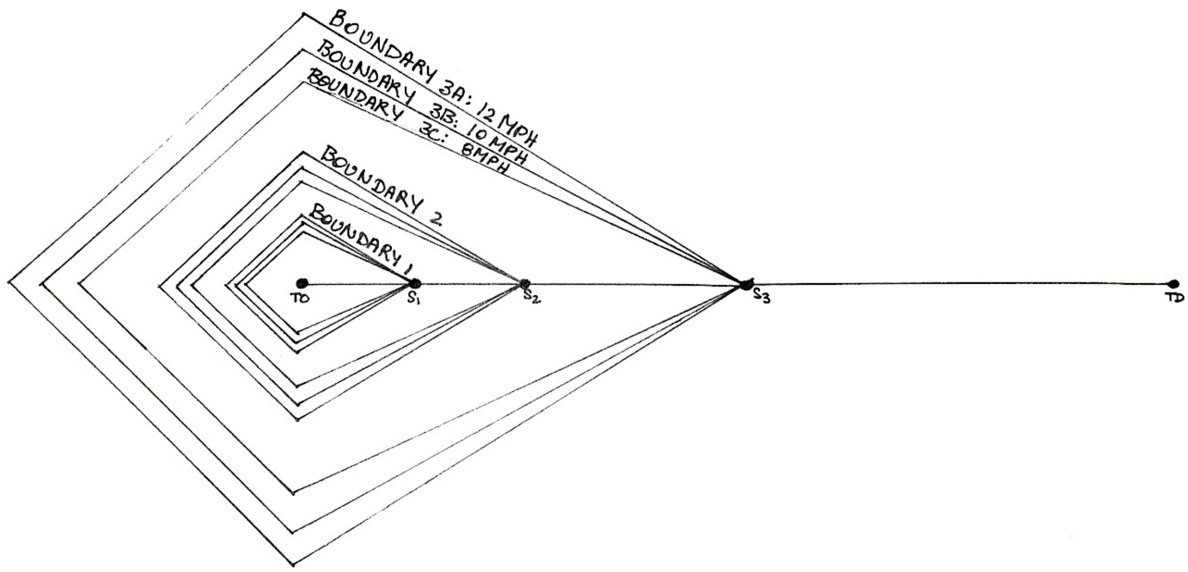

Figure 2: Theoretical Travel Time Boundaries

OpenTripPlanner's Batch Analyst tool was used to calculate a region-wide travel time matrix at the census block level via the Nice Ride system, as well as specific route measures for trips reported in the survey. The calculations used an assumption of 5 $^{\mathrm{km}}/_{\mathrm{h}}$ for walking speed and 16 $^{\mathrm{km}}/_{\mathrm{h}}$ for biking.

The travel time matrix was used to measure job accessibility from every census block in the region at 5 to 60-minute time thresholds.

A conditional logit model was used to predict which station each respondent used as a function of trip characteristics and built environment features around each station. The choice set for each respondent included the five closest stations to their true starting point; about 99% of trips in our sample started from a station in the choice set.

Results

Accessibility

Bike-share stations provided an increase in accessibility to jobs relative to walking at medium and high time thresholds. For short thresholds (e.g., 5 to 10 minutes), the cost of walking to a station to retrieve a bike consumed too much of the travel time budget, resulting in fewer jobs being accessible by Nice Ride than by walking directly. At 15 minutes, using Nice Ride provides access to 1.7 times as many jobs as walking on average in blocks that are within a 15-minute walk to a station. The peak advantage occurs at 30 minutes, where bike-share provides access to 221% more jobs than walking.

Figure 3 shows where bike-share has the strongest advantage at the 40-minute threshold. Yellow and brown areas indicate higher job accessibility by bike-share than walking, and pink areas

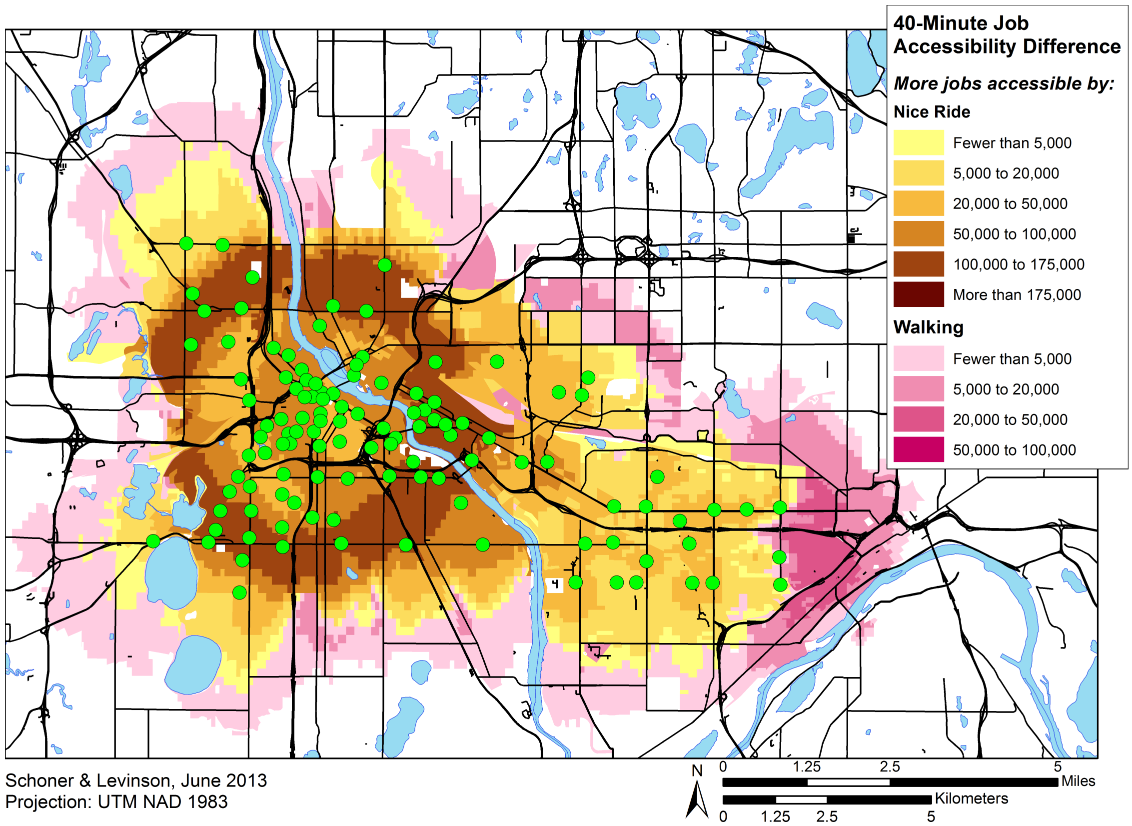

Figure 3: 40 Minute Job Accessibility Difference between Nice Ride and Walking

indicate the reverse. In downtown Minneapolis and immediately surrounding neighborhoods, bike-share improves job accessibility, but the areas are dense enough that walking still provides access to a large number of jobs. The dark brown ring shows the boundary where the utility of walking declines and bike-share remains high. Much of this area is lower density with fewer jobs, and it is too far from downtown for pedestrians reach it within the threshold. Bike-share's higher travel speeds continue to enable people with access to a station to reach major job centers in and near downtown. Although downtown St. Paul also has a high concentration of jobs, the distribution of stations at the end of the 2011 season did not extend far enough to provide a benefit over walking.

Station Choice

For all trip types, deviation from the direction of travel was a significant predictor in a station's probability of being chosen. A station that requires 100 additional meters travel in the "wrong" direction is 18.2 to 27.9% less likely to be chosen, depending on trip purpose.

Measures of walking were significant for both commute and non-work trips, but the type and magnitude of these measures differed. Non-work trips started from stations that increased the share of a trip spent biking (versus walking); each percentage point increase in walking time decreased that station's odds of being chosen by 10.3%. Commuters were more likely to choose the closest station possible, regardless of trip length or bike/walk ratio, and the effect was much stronger than for non-work travelers (52.3% per additional minute).

Crime had a small but significant effect on commuters and non-work users alike. Commuters favored stations closer to parks. Income was weakly significant for non-work users: surprisingly, stations in higher income neighborhoods were *less* likely to be chosen.

Conclusions

This study demonstrated the use of measuring accessibility improvements provided by a bike-share system relative to a baseline of walking. Our results showed that job accessibility via bike-share does not improve relative to walking for very short trips due to the additional time spent walking to and from the station. For time budgets of 15 minutes or longer, however, bike-share stations expand a person's access to jobs and other opportunities considerably relative to walking.

We also found that for job accessibility, stations placed around the periphery of the central city provided a substantial improvement in job access for Minneapolis due to the high concentration of both jobs and stations downtown. St. Paul, lacking "receiving" stations in the central business district, did not see the same improvement in job accessibility due to bike-share.

The results and method of the accessibility portion of the study may be used to help planners and public administrators plan and optimize their bike-share systems for maximum impact. While this study focused on accessibility to jobs, the same strategy could be used to identify the best places to add stations to improve accessibility to parks, grocery stores, or tourist attractions. Further study is needed to evaluate how strongly the system's accessibility correlates with increased use.

The station choice modeling revealed how individuals start their trips within the bike-share system and what features improve a station's utility. In general, travelers avoid deviating from the most direct path of travel. For all trip purposes, people choose stations that reduce walking, whether in absolute terms (commuters) or relative to the total trip composition (non-work trips). These findings may be useful for determining station placement strategy. Spacing stations evenly may provide the most people with *some level* of access, but clustering them around key trip generators and attractors may increase use by maximizing the number of people who have *easy* access to the system. Future research is needed to evaluate the egress segments of trips and the routes people use via bicycle in between.

Chapter 1

Introduction and Key Issues

1.1 Introduction

Bicycle-sharing systems are an emerging trend in the United States and worldwide. Cities are jumping on the trend in response to promises that bike-share will induce mode shift, alleviate congestion, promote active and healthy lifestyles, and spawn economic development. However, as cities embrace the systems, our understanding about how people actually integrate these systems into their daily travel is limited.

Through this research, we attempt to fill some of this knowledge gap by studying how people navigate from place to place using the Nice Ride Minnesota bike-share system in the Minneapolis-St. Paul metropolitan area (Twin Cities). Section 1.2 describes job accessibility in the context of bike-share stations. In Section 1.3, we develop a theoretical model for bike-share station choice inspired by examples from public transit. Section 2 reviews the methodology used to measure bike-share accessibility and test theories about bike-share station choice empirically.

In Section 3, we present findings from calculating accessibility improvements from bike-share stations and the results from two sets of conditional logit models. The accessibility calculations in Section 3.1 highlight where bike-share has the strongest relative advantage to walking. The models in Section 3.2 demonstrate factors associated with choosing a given station for both commute trips and non-work trips made by Nice Ride. The models fit the data well, and several of the findings confirm expectations. People do in fact prefer to use stations that do not require long detours out of the way to access. However, commuters and non-work travelers differ in how they value the walking portion of their trip, and what station amenities and neighborhood features increase a station's utility.

Finally, in Section 4, this paper concludes with a discussion of how these results impact current practice and ongoing research, as well as areas for further development or improvement. The results from this study will be important for planners who need a better understanding of where bike-share has the strongest potential for accessibility benefits, and how bike-share users choose stations in order to design or optimize their system. Understanding people's relative preferences for walking and biking within a single bike-share trip provides guidance for system expansion and densification, and enriches forecasting methodology by demonstrating a distribution of typical walking distances associated with accessing a bike-share station. The results also demonstrate that the surrounding location plays an important role as well. Notably, proximity to parks and the local crime rate around the station are significantly associated with the likelihood of any given station being chosen for a trip. The findings also provide a strong foundation for future study about comprehensive route choice analysis of this new bicycling technology.

1.2 Theoretical model of station accessibility

Accessibility measures the opportunities available to a person at a point in space, and the ease with which the individual can reach those opportunities.

For origins $i = 1 \dots n$ and destinations $j = 1 \dots m$, the accessibility of i is described by Equation 1.1.

$$A_i = \sum_j O_j \times f(C_{i \to j}) \tag{1.1}$$

where:
$A_i =$ Accessibility of block i
$O_j =$ Opportunities at destination block j
$f(C_{i \to j}) =$ Weighting function based on the cost of travel from i to j

Cumulative opportunity accessibility provides a raw count of the number of opportunities that can be reached within a specified time threshold. In this case, the weighting function $f(C_{i \to j})$ is simply a binary function indicating whether the travel time between i and j ($t_{i \to j}$) is within some threshold T. As shown in Equation 1.2, opportunities at destinations within the threshold are counted, while opportunities outside the threshold are not.

$$f(C_{i,j}) = \begin{cases} 1 & \text{if } t_{i,j} \leq T \\ 0 & \text{otherwise} \end{cases} \tag{1.2}$$

Bike-share trips are comprised of three segments:

1. Station access walking trip
2. One or more on-bicycle segments between stations
3. Station egress walking trip

This complicates accessibility calculations because the travel cost is the sum of the costs of these three segments. To account for these, the cost function $f(C_{i \to j})$ for a bike-share trip becomes:

$$f(C_{i \to j}) = \begin{cases} 1 & \text{if } w * d_{i \to s_i} + b * d_{s_i \to s_j} + w * d_{s_j \to j} \leq T \\ 0 & \text{otherwise} \end{cases} \tag{1.3}$$

where:
$w =$ Walking speed

b = Bicycling speed
$d_{x \to y}$ = Network distance between any two points x and y
s_i = Station closest to origin i
s_j = Station closest to destination j

Notably, this framework forces the traveler to use the bike-share system even if the traveler may enjoy higher levels of accessibility by walking directly to opportunities. Existing research on transit accessibility solves this issue by calculating the accessibility of walking plus transit combined (how many jobs one can reach by either walking to a transit stop or walking directly to a destination with jobs) [7]. However, the bicycling segment of a bike-share trip is typically shorter and slower than the on-vehicle segment of a transit trip, so the walking accessibility values cause relatively more distortion for bike-share than transit. Additionally, measuring strict bike-share accessibility separately from walking accessibility enables a comparison of where bike-share provides the largest accessibility improvement over a baseline of walking.

1.3 Theoretical Model of Station Utility and Choice

1.3.1 Bike-share and Transit route choice

Bike-share is an on-demand system: bicycles are available at any time of day or night. Despite this temporal difference with transit, the spatial structure of a person's route through the system is similar.

Bike-share trips, like transit, are comprised of three primary segments:

1. Station access walking trip
2. One or more on-bicycle segments between stations
3. Station egress walking trip

These segments are by definition anchored to two or more of the stations within the system. Because of this similarity, research about accessing transit stations provides some guidance bike-share.

Several studies have explored mode choice for the station access and egress segments of transit trips, while assuming the station choice is fixed [2, 5]. Despite leaving out this station choice element, these studies provide insight into how people value travel time between several access modes to the station. Given that one component of bike-share station choice is how people relatively value travel time spent walking versus biking, these findings are interesting. Chalermpong et al. found that the cumulative share of travelers arriving at a station by motorcycle taxi overtakes walking at about 0.7 kilometers (km), or about 0.43 miles per hour (mi) from the station, and increases drastically beyond 0.9 km (about 0.56 mi) from the station [2]. Hsiao et al. reported on what share of passengers using a transit station walked from a range of distances [5]. Notable drop-offs occur at 0.25 mi, or about 0.4 km, and 0.75 mi (about 1.2 km).

Guo et al. modeled subway commuters' station egress routes of Boston subway commuters from an on-board transit survey [3]. They identified two possible paths for each participant: One where the traveler may avoid a transfer by having a longer walk time, and another where the traveler transfers between routes and has a shorter walk time. Because the paths originated from different transit stations, route overlap between paths was minimal, avoiding the Independence of Irrelevant Alternatives condition that challenges many route choice studies. They found that paths through Boston Common (open space/parkland) increased the utility of the trip by 2.9 minutes, while paths through hilly terrain decreased utility by 3.5 minutes. Collectively, all their pedestrian environment variables increased pedestrian utility by about 21 to 33%, shifting the balance of how many people would choose the longer walking path based on travel time advantage alone.

Further underscoring the importance of relative durations of walking and bicycling is research into how transit passengers perceive time spent in different stages of their trips [10]. Bovy et al. address this in their study of transit route choice [1]. They model each segment, including the access and egress trips, station choice, and main route segment using a set of Multi-Nested Generalized Extreme Value Models (GEVs). The station choice component of their models focused on the caliber of service provided there: inter-city or local.

Unlike transit, the user has significantly greater flexibility to choose stations and routes in between that satisfy her preferences for travel time savings, minimizing (or possibly maximizing) physical exertion, or even just a pleasurable riding environment.

Figure 1.1 maps a hypothetical scenario with several bike-share stations and several transit stations connecting the same origin (TO) and destination (TD). This illustrates the system's flexibility, and underlines how complex this makes the study of bike-share user route choice. The traveler could use any of the three closest bike-share stations. The closest station requires walking away from the destination for a short distance. The most direct station is also the farthest away and would require the most walking. Finally, the third nearby station demonstrates additional station amenities that may make the station more attractive. In this scenario, the bike ride along the park may be more comfortable or easier than the bike ride along the main street. As a point of comparison, only a few of the nearby transit stations are appropriate for the trip between TO and TD, as many are either connected to the wrong route or the wrong direction of the correct route.

1.3.2 Relative Station Position

For the station choice scenario, let us temporarily assume that utility is derived solely from travel time savings, not from station amenities or individual characteristics. These other factors will be included in the final model, but the conceptual framework is easier to visualize by focusing strictly on travel time. A trip is comprised of a walking segment from the individual's origin to their originating station, a bicycling segment from the originating station to the arriving station, and another walking segment from the arriving station to the individual's destination. Since we are focusing strictly on station origins in this paper, the second and third segments will be regarded as one.

As shown in Figure 1.1, when an individual starts a bike-share trip, they may have several nearby stations to choose from. These stations vary in distance from the individual's origin, distance to the individual's destination, and the amount of deviation from a "shortest path" route

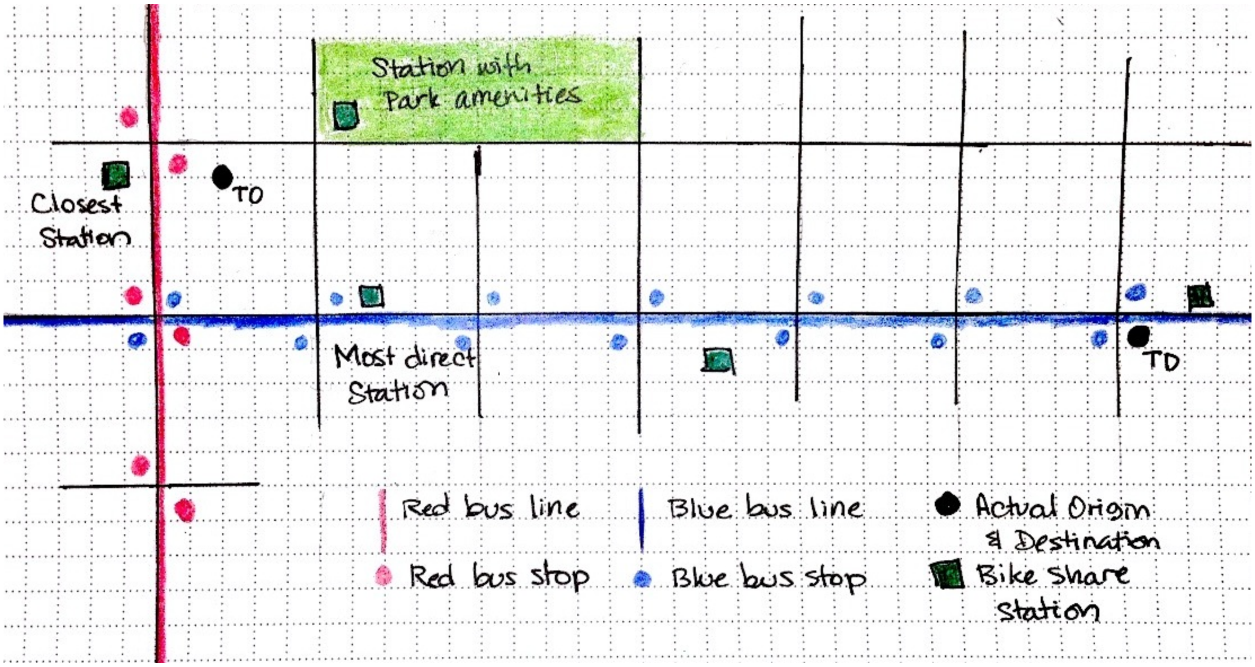

Figure 1.1: Hypothetical Transit Stations versus Bike-Share Stations. Any of the bike-share stations can be used to travel from TO to TD, but only a small number of bus stops are eligible.

between the origin and destination that is required to utilize that station.

Depending on the individual's relative walking and bicycling speeds and their respective preferences for each mode, they may be faced with a decision to walk to the closest station which requires detouring from the shortest path, or else walking a longer distance to use a station that minimizes overall travel distance.

Figure 1.2 shows three sets of equal travel time boundaries that vary with walking and bicycling speed. These boundaries show the relative value of retrieving a bicycle from the closest station versus walking farther in the direction of travel. Figure 1.3 shows one of these boundaries overlaid on a hypothetical grid network.

An individual starting from position TO (true origin) to position TD (true destination) with an average walking speed w and average bicycling speed b, assuming a grid-like street network, will find that they achieve equal travel time by selecting a station anywhere along one of the boundaries that corresponds to their travel speed.

For the 2 miles per hour trip from TO to TD in Figure 1.2, consider the station located at position S_3, halfway between the origin and destination and directly along the shortest path of travel. An individual with $w = 3\ {}^{\mathrm{mi}}/_{\mathrm{h}}$ (about 5 ${}^{\mathrm{km}}/_{\mathrm{h}}$) and $b = 12\ {}^{\mathrm{mi}}/_{\mathrm{h}}$ (about 19 ${}^{\mathrm{km}}/_{\mathrm{h}}$) can achieve equal travel time by either walking one mi (about 1.6 km) east to retrieve a bicycle and biking the remaining miles per hour, or walking 0.6 mi (about 1 km) west, even though the latter alternative increases their overall travel distance by more than $\frac{1}{3}$.

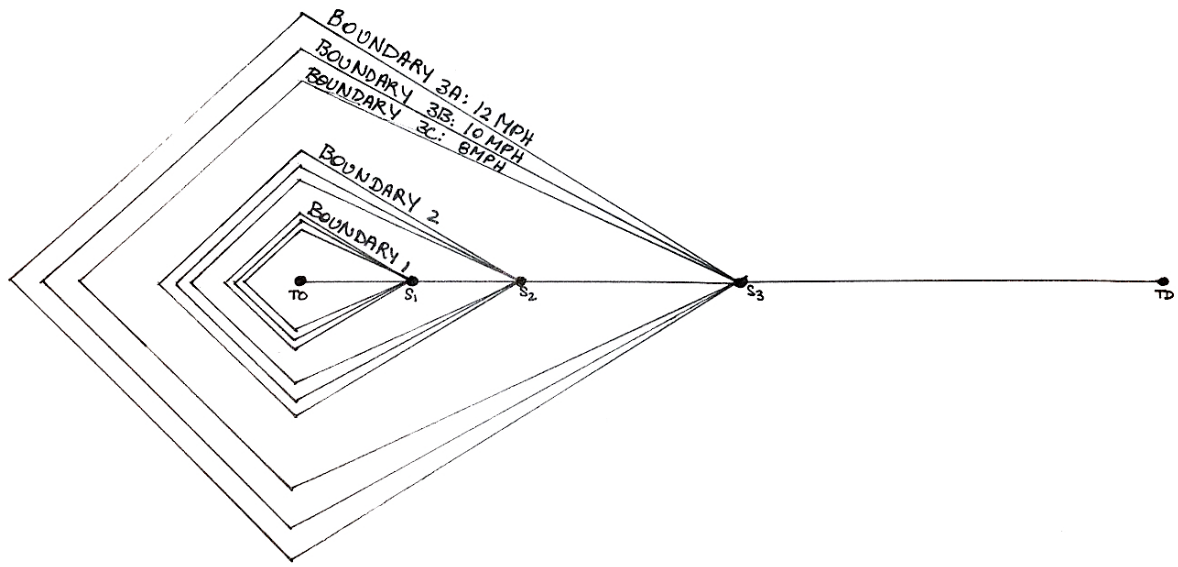

Figure 1.2: Theoretical Equal Travel Time Boundaries. A person starting at TO experiences equal travel time if they use station S_3 or any other station placed along Boundary 3A, 3B, or 3C depending on their travel speeds.

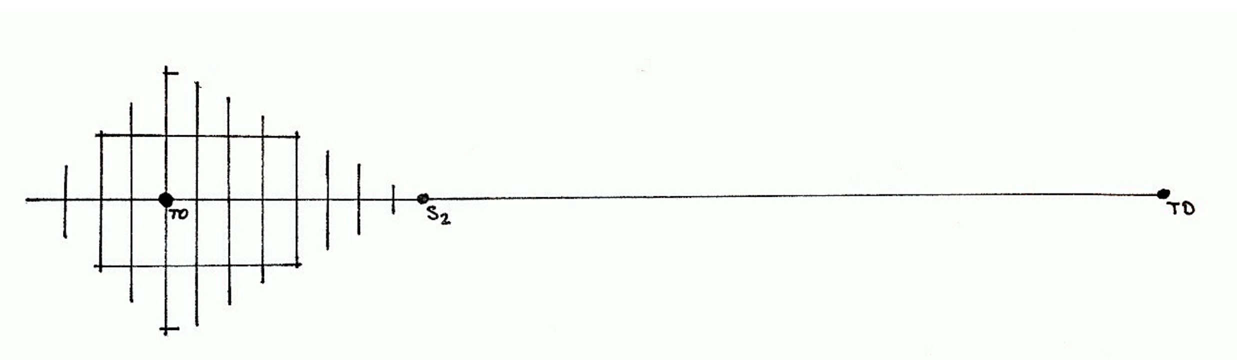

Figure 1.3: Theoretical Equal Travel Time Grid. A station placed anywhere on the grid network will provide equal or better travel time accessibility between TO and TD as station S_2.

1.3.3 Conditional Logit choice model

Given the complexity of variables potentially influencing a person's choice of station, the conditional logit model structure is a natural fit for the data. The stations available to each participant are not ordered, ranked, or labeled in a way that would be conducive to multinomial logistic regression. The choice set for each participant is unique to their origin, so the stations are identified solely by their attributes as they relate to the individual and their trip.

Conditional logit analysis is a generalized form of the binary logit formulation for modeling discrete choices [6]. The underlying assumption for discrete choice models is that an individual chooses the alternative that they believe will maximize their utility subject to the errors in perception. Therefore, the selection probability of any given choice is equal to the probability that the individual perceives it to have the highest utility, which is a function both of attributes describing the choice and of the individual herself. McFadden defines utility in this context using Equation 1.4 [6]:

$$U = V(s, x) + \varepsilon(s, \beta) \tag{1.4}$$

where s is a vector of attributes describing the individual, β is a vector of attributes describing each of the alternatives, and v and ε are functions describing typical population preference and the idiosyncratic preferences of the individual, respectively [6].

In the station choice problem, each alternative has a set of defining attributes (independent variables). Random errors capture individual variation.

Chapter 2

Methodology

2.1 Survey

The data come from an online survey of Nice Ride Minnesota bike-share subscribers conducted as part of another study about economic activity around bike-share stations [8, 9]. Nice Ride Minnesota emailed an introductory letter and survey link to 3,693 monthly and annual subscribers in May 2012. We received 1,197 valid surveys, for a response rate of 30%.

The survey focused primarily on aggregate trip behavior, such as the frequency with which the respondent visited various types of destinations via Nice Ride. The final section of the survey invited respondents to report the geographic details of specific trips they recently completed using Nice Ride bikes. These records captured the respondent's origin, the station they used at the beginning of their trip, the station at which they returned their bike, and their final destination, along with a verbal description of the route each participant rode and the purpose of the trip. A copy of the survey instrument used to collect trip records is available on pages 54 to 57 of [8].

2.2 Station Accessibility Measures

We measured cumulative opportunity accessibility to jobs at the census block level using the Nice Ride system, with thresholds from 5 minutes to 55 minutes in 5-minute increments. Nice Ride accessibility measures the number of jobs a person can reach by walking from the centroid of a census block to the nearest bike-share station, biking to any other station in the system, and walking to a census block containing jobs nearby.

Travel distances were measured using OpenTripPlanner (OTP) Batch Analyst on an OpenStreetMap (OSM) network extract of the Minneapolis-St. Paul Metro Area. Origins and destinations were defined as the centroids of census blocks within 5 km or about 3.1 mi (network distance) of a Nice Ride station. Station locations at the end of the 2011 season were provided by Nice Ride Minnesota. Travel times were then calculated using an assumed average bicycling speed of 16.1 $^{\mathrm{km}}/_{\mathrm{h}}$ (10 $^{\mathrm{mi}}/_{\mathrm{h}}$) and walking speed of 5 $^{\mathrm{km}}/_{\mathrm{h}}$ (3.1 $^{\mathrm{mi}}/_{\mathrm{h}}$). Job counts at each census block came from the 2010 Longitudinal Employer-Household Dynamics (LEHD) survey. For this portion of the study, it is assumed that an individual will always choose the closest station to their origin and destination, regardless of the direction of travel. The Nice Ride accessibility calculation assumed that the individual would use the Nice Ride system, even if they could access a larger number of jobs simply by walking directly.

For comparison, we also measured job accessibility by walking at the same time thresholds. Walking accessibility was calculated using the same data inputs, programs, and assumptions as Nice Ride accessibility. The difference between walking and Nice Ride accessibility for each block at a specified time threshold ($A_{i,t}^{\text{diff}}$) was calculated by subtracting the number of jobs accessible by walking from the number of jobs accessible via Nice Ride, shown in Equation 2.1.

$$A_{i,t}^{\text{diff}} = A_{i,t}^{\text{NR}} - A_{i,t}^{w} \tag{2.1}$$

where:
$A_{i,t}^{\text{NR}}$ = Number of jobs accessible via Nice Ride from block i within t minutes
$A_{i,t}^{w}$ = Number of jobs accessible via walking from block i within t minutes

2.3 Station Choice Model

2.3.1 Survey Trips

597 respondents agreed to complete the final section and report one or more (up to five) trips. These records were manually geocoded using a combination of Google Maps and ESRI ArcGIS 10.1. Each trip record contained three or more segments: a station access segment between the respondent's origin and the originating station they used, one or more bicycling segments between stations, and another station access segment between the final station and the respondent's destination. Due to the open-ended questions used in the survey instrument, many trip records were incomplete or unidentifiable. The resulting dataset contained 506 complete trip records. An additional 10 were removed because their trip started and ended at the same location (round trip).

2.3.2 Choice Set

Each geocoded trip was matched to the specific stations that the participant used. OpenTripPlanner's batch analyst tool was used to calculate the distances between all stations and each person's origin and destination. Trips were then flagged by whether they used the closest station to their origin, or another station. Table 2.1 shows the frequency of people starting their trip by using the i^{th} closest station. As the table shows, the vast majority of trips (82.6%) use the station closest to the origin, and 98.8% of trips use a station ranked 5^{th} or closer. Therefore, we constrained the choice set to include only the five closest stations to each origin, measured in minutes walking at 5 $^{\text{km}}/_{\text{h}}$. The dependent variable is a binary indicator of whether that particular station is the one that the traveler used as part of their trip.

Table 2.1: Frequency of choosing the i^{th} closest station

Rank i	Not Chosen	Chosen	Pct. Chosen	Cumulative Pct.	Total
1	90	418	82.6%	82.6%	508
2	447	57	11.3%	93.9%	504
3	493	18	3.6%	97.4%	511
4	496	6	1.2%	98.6%	502
5	509	1	0.2%	98.8%	510
6 to 10	2,534	5	1.0%	99.8%	2,539
11 to 20	4,912	1	0.2%	100.0%	4,913
21 and higher	20,563	0	0.0%	100.0%	20,563
Total	30,044	506	100.0%	100.0%	30,550

2.3.3 Explanatory Variables

A summary of the explanatory variables is available in Table 2.2. A simple t-test results shows which variables have a significant difference between the stations people chose as parts of their trip and the stations that were selected to comprise each person's choice set.

Measures derived from trip length

The length and duration of each trip segment in the choice set was measured using OpenTripPlanner's Batch Analyst and street network file downloaded from OpenStreetMap. Batch Analyst uses an algorithm to identify the shortest path between sets of origins and destinations and calculates a travel time. We assumed a walking speed of 5 km/h (3.1 mi/h) and a bicycling speed of 16 km/h (10 mi/h).

The travel time (in minutes) from the participant's origin to each station in their choice set was included in the model. Additionally, a ratio of walking time to total trip time (walking + biking) was included. These two variables capture people's absolute and relative preferences for time spent walking versus biking.

The straight-line distance between the true origin, stations, and true destination was calculated in meters using PostGIS. A measure of deviation from the shortest path was calculated by subtracting the direct distance between origin and destination (S_0) from the combined distance of origin to station (S_1) and station to destination (S_2), as shown in Equation 2.2. Figure 2.1 shows these segments on a hypothetical trip.

$$(S_1 + S_2) - S_0 \tag{2.2}$$

Station Area Amenities

The presence of a bike trail and proximity to parks were included in the model to identify whether station area amenities increased the utility of a particular station. Trails are measured with a

Table 2.2: Variable names, units, and summary statistics for all variables included in modeling. The final column shows the results of a t-test comparing chosen stations to stations selected to be in the choice set for each person.

			Chosen stations		Non-chosen set		Significant
	Variable Definition	Units	Mean	(S.D.)	Mean	(S.D.)	Difference
C	Chosen station	Binary	(Dependent Variable)				
W	Walk Time to Station	Minutes	2.83	(2.77)	10.00	(6.09)	***
R	Ratio of Walk to Total Travel Time	Percent	25.19	(18.25)	55.00	(17.28)	***
D	Deviation from Shortest Path	Meters $*$ 100	1.31	(1.87)	5.48	(5.28)	***
T	Trail within $\frac{1}{4}-$mi of station	Binary	0.41	(0.49)	0.33	(0.47)	***
P	Distance to Park	Meters $*$ 100	2.13	(1.67)	2.26	(1.79)	*
V	Violent crime rate	Count per 10,000 Residents	61.39	(76.75)	56.54	(70.43)	*
M	Median Household Income	USD $*$ 1,000	\$47.87	(\$24.63)	\$46.78	(\$24.07)	

*** Significant at the 0.01 level
** Significant at the 0.05 level
* Significant at the 0.1 level

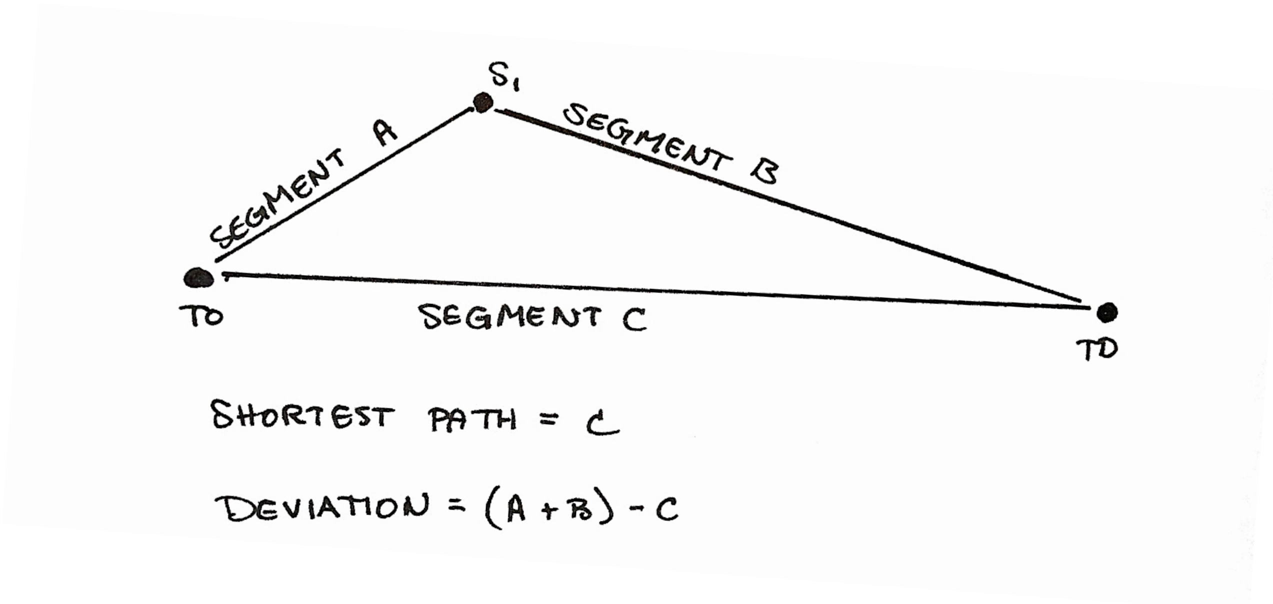

Figure 2.1: Measuring Deviation from Shortest Path

dummy variable for whether a bike trail passes through a 400-meter ($\frac{1}{4}$—mi) network distance buffer around each station. Proximity to park land is measured in meters.

Neighborhood Characteristics

Crime rates and median household income were added to control for social variables that may encourage or discourage a person from using a particular station. Local crime statistics from the Minneapolis and St. Paul police departments were measured at the neighborhood level as the number of violent crimes that occurred per 10,000 people in 2010. Each station assumes the crime rate of the neighborhood that contains it. While neighborhoods are a much coarser resolution than preferred, data were not available in a more disaggregated format. To account for Downtown Minneapolis having both the highest crime rate and the largest concentration of stations and bike-share activity, an interaction variable between crime rate and Downtown was created. The model includes a measure of crime rate *outside* the central business district only. Median household income is similarly measured at the neighborhood level, with the station assuming the median income of the neighborhood that contains it.

Trip Purpose

Trip purpose can change the priorities people have while traveling. Someone on their morning commute may prioritize travel time savings above all else, whereas someone taking a bike out on their lunch break to get some fresh air may value other characteristics. To account for this possible difference, we modeled commute trips and non-work trips separately.

Individual Characteristics

Data about each member's age and gender were available from electronic trip records provided by Nice Ride for matching with survey data. Several interaction variables between age, gender, and the walking and deviation variables were tested and ultimately excluded due to insignificance.

Chapter 3

Results

3.1 Station Accessibility Measures

3.1.1 Descriptive Statistics

Job accessibility was calculated for each census block using either Nice Ride or walking at a range of time thresholds. Table 3.1 summarizes how many blocks in the Minneapolis-St. Paul Metropolitan Area (Twin Cities) within 5,000 meters of a Nice Ride station have job accessibility by walking or Nice Ride. As one would expect, fewer census blocks have any job accessibility via Nice Ride at lower time thresholds because the time cost of accessing a Nice Ride station may exceed the threshold. At a ten minute accessibility threshold, 77.4 % of blocks with any jobs accessible via Nice Ride still provide greater accessibility by walking directly. With a longer allowable accessibility threshold, however, Nice Ride provides an improvement over the walking baseline, both in number of blocks with any job accessibility and the share of blocks where Nice Ride accessibility exceeds that of walking directly.

Table 3.1 also summarizes average accessibility levels at a range of time thresholds. For example, at a ten minute threshold, the average number of jobs one can reach via Nice Ride from blocks that provide both Nice Ride and walking accessibility is 4,923, and the average for walking in these same blocks is 4,793. Accessibility levels by walking and Nice Ride generally increase as the time threshold grows, although at the fifty minute threshold, some blocks on the periphery that could not access the system at shorter thresholds now have low levels of accessibility by Nice Ride, reducing the overall average. In blocks with both Nice Ride and walking accessibility, Nice Ride on average provides access to between 0.50 and 3.21 times as many jobs as walking.

3.1.2 Spatial Comparison

Maps of Nice Ride accessibility, walking accessibility, and the difference between the two were produced for eleven time thresholds between 5 and 55 minutes, in 5 minute increments. This section presents several maps and interprets the results. The full collection of maps is available in the appendix.

Table 3.1: Average Job Accessibility by Nice Ride and Walking

	5 Min.	10 Min.	15 Min.	20 Min.	25 Min.	30 Min.	35 Min.	40 Min.	45 Min.	50 Min.	55 Min.
Number of blocks with at least one job accessibile by …											
Nice Ride[1]	388	2,216	3,591	4,432	5,098	5,779	6,439	7,115	7,722	8,419	9,133
Walking Only	5,504	4,328	3,299	2,721	2,418	2,017	1,720	1,390	1,212	873	534
All Blocks	5,892	6,544	6,890	7,153	7,516	7,796	8,159	8,505	8,934	9,292	9,667
Percent of blocks with at least one job accessibile by …											
Nice Ride	6.6%	33.9%	52.1%	62.0%	67.8%	74.1%	78.9%	83.7%	86.4%	90.6%	94.5%
Walking Only	93.4%	66.1%	47.9%	38.0%	32.2%	25.9%	21.1%	16.3%	13.6%	9.4%	5.5%
All Blocks	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Average number of jobs accessible by Nice Ride in blocks with …											
Nice Ride	780	4,923	14,801	31,443	53,067	68,918	75,661	76,459	75,576	73,108	70,195
All Blocks[2]	51	1,667	7,714	19,482	35,995	51,087	59,711	63,963	65,323	66,239	66,317
Average number of jobs accessible by Walking in blocks with …											
Nice Ride	1,581	4,793	8,363	13,309	19,400	25,694	32,342	39,350	46,735	53,289	59,372
Walking Only	342	845	1,689	2,419	2,373	1,963	1,718	1,258	885	709	449
All Blocks	423	2,182	5,168	9,166	13,922	19,554	25,886	33,124	40,514	48,349	56,117
Average Ratio of Nice Ride to Walking Accessibility											
Nice Ride	0.50	0.83	1.70	2.34	3.12	3.21	2.66	2.06	1.64	1.34	1.13
All Blocks	0.03	0.28	0.88	1.45	2.12	2.38	2.10	1.73	1.42	1.21	1.07

[1] All blocks that have Nice Ride accessibility also have walking accessibility.

[2] The “All Blocks” average includes all blocks with walking accessibility at that time threshold, regardless of whether they have any Nice Ride accessibility, as the denominator.

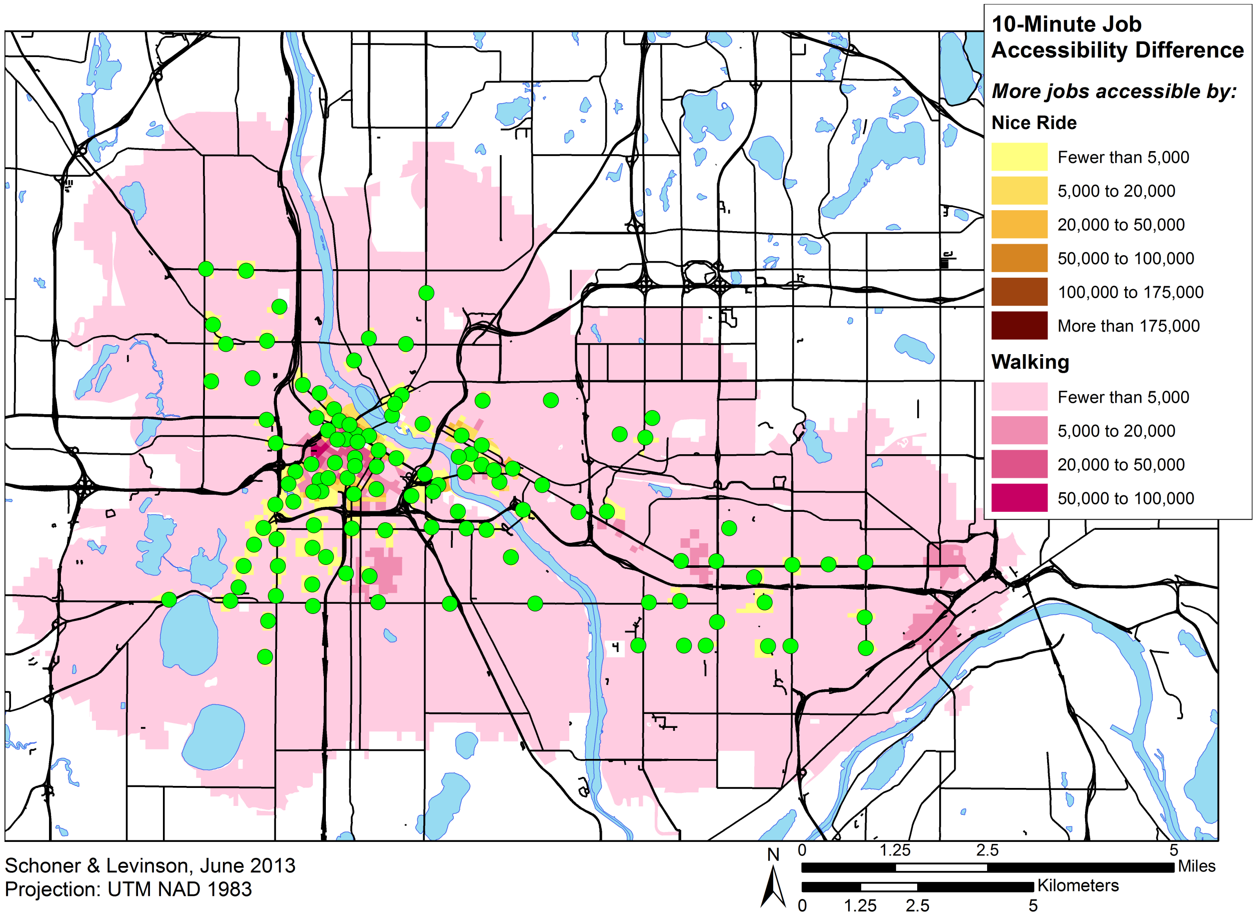

Figure 3.1: 10 Minute Job Accessibility Difference between Nice Ride and Walking

Figure 3.1 shows the accessibility difference (refer to Equation 2.1) between Nice Ride and walking at the ten minute threshold. Darker shades of brown indicate a larger number of jobs accessible by Nice Ride versus walking. Darker shades of pink indicate a larger number of jobs accessible by walking than Nice Ride. The Nice Ride stations only provide a marginal improvement in job accessibility over walking in a small handful of blocks. Most of these are clustered around, but not in, Downtown Minneapolis, with some corridors extending into South Minneapolis. These are areas where the bike-share network is the most built-up, so Nice Ride has greater potential to improve accessibility conditions above the walking baseline. The tan blocks around the edge of the Central Business District (CBD) indicate the boundary where walking is no longer sufficient to reach the major job centers of Downtown Minneapolis.

At higher time thresholds, a dark ring around central Minneapolis emerges where Nice Ride provides access to 100,000 to 175,000 more jobs than walking. The ring starts to appear at the 25-minute threshold (Figure 3.2), but is most distinct at 40 minutes (Figure 3.3). The dark ring shows a zone where one cannot walk to the CBD within 40 minutes, but the Nice Ride system provides Downtown access, and therefore significantly improved job accessibility.

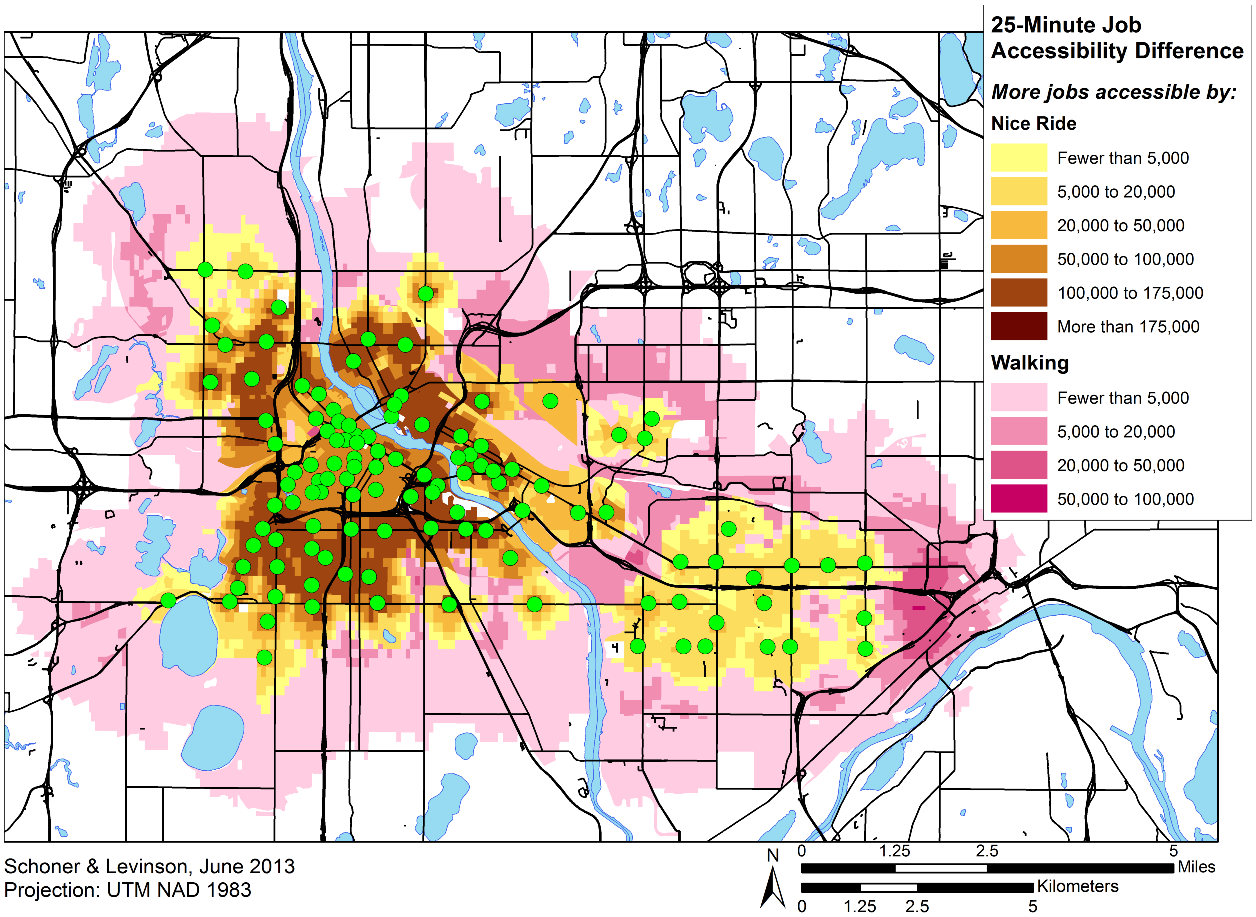

Figure 3.2: 25 Minute Job Accessibility Difference between Nice Ride and Walking

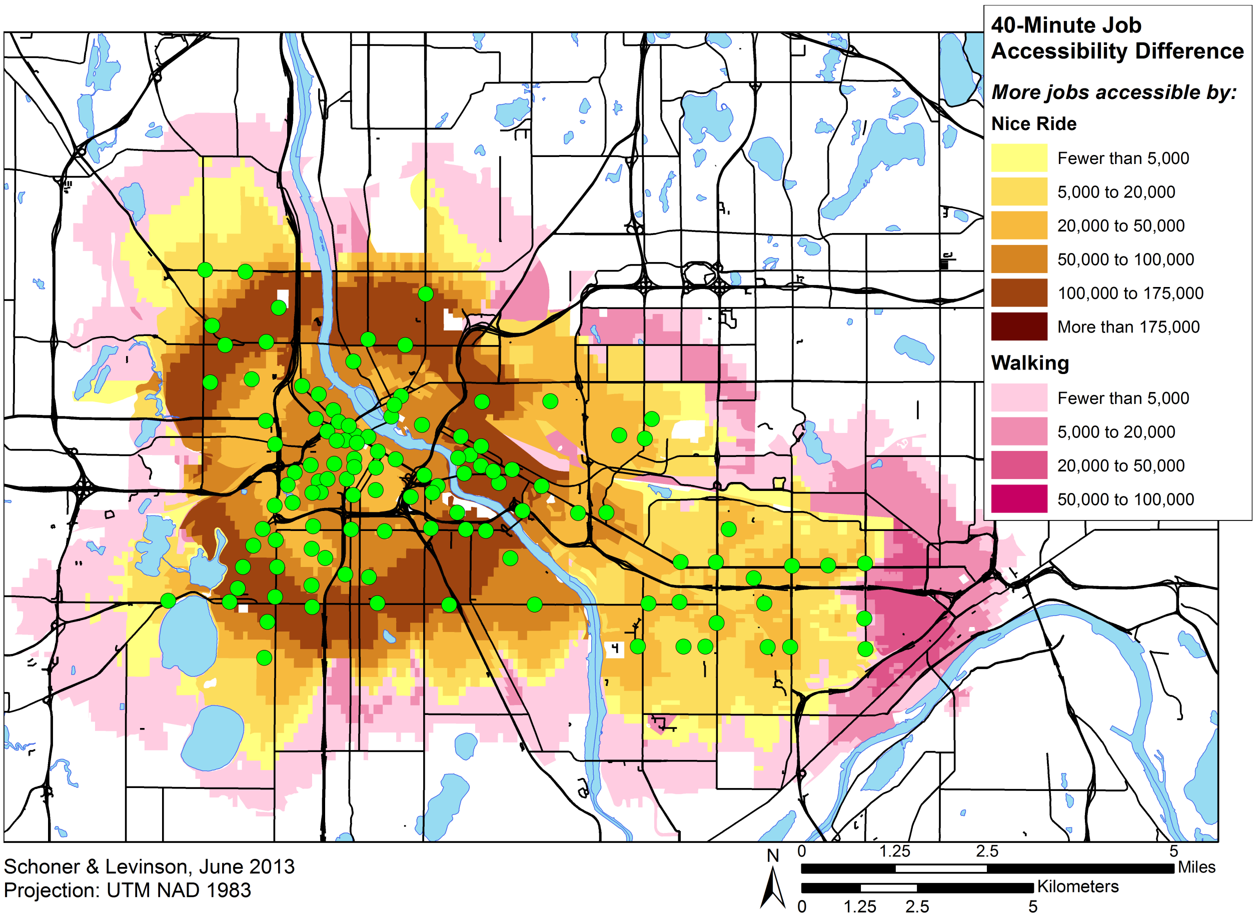

Figure 3.3: 40 Minute Job Accessibility Difference between Nice Ride and Walking

3.2 Station Choice Model

3.2.1 Model Fit

Table 3.3 shows the results from modeling station choice for commute and non-work trips. The first model, "Base Model" includes only the walking and deviation variables. The "Full Model" controls for proximity to a bike trail and parks, crime rates for stations outside the CBD, and median household income in the neighborhood containing the station. The final column shows a more parsimonious model where control variables with p-values greater than 0.1 were removed stepwise in order from highest p-value to lowest, followed by walking or deviation variables under the same criteria.

McFadden's Pseudo$-R^2$ and Bayesian Information Criterion (BIC) are reported for all models. The commute models have Pseudo$-R^2$ values ranging from 0.724 to 0.758. The non-work trips have slightly lower Pseudo$-R^2$ values, from 0.700 to 0.708, possibly because people experience greater time pressure on commute trips, and other amenities matter less in station choice. Overall, these values are high, suggesting that the fitted models are all substantial improvement over the null models. In both commute and non-work trips, most of the improvement over a null model comes from the walking and linear deviation variables. Controlling for station amenities and neighborhood characteristics provides only a marginal improvement. BIC assesses model fit with a specific emphasis on penalizing the addition of superfluous variables that marginally improve the log-likelihood without contributing any meaning. The BIC for both commute and non-work trips suggest that the additional parameters in the full model do not add significant value, and either the base model or final model are preferable.

3.2.2 Commute Trips

Travel time to the station, deviation from the shortest path, proximity to parks, and crime outside the CBD are all significantly associated with choosing a particular station at the beginning of a commute trip. The conditional logit regression coefficients represent the change in log-odds of choosing a station based on a 1-unit change in the independent variable, so the odds ratios are also presented for ease of interpretation. In the final model, each additional minute required to walk to a station is associated with a -0.741 decrease in the log-odds of choosing that station. Put another way, that station is 47.7% as likely to be chosen as one that is one minute closer.

Interestingly, the absolute measure of walking (minutes) is significant in the final model, but the ratio of walk time to total trip time disappears. The deviation from the shortest path variable is also significant. From this we can infer that commuters value shorter trips, and have a threshold above which they prefer not to walk. But the relative balance of walking and bicycling in any given trip is irrelevant, as long as the travel times meet the other criteria.

Proximity to parks appears to be an important factor, and these findings are consistent with [4]. For commuters, the park may increase the station's utility by making the walk to and from the station more pleasurable. Alternatively, it could simply be a function of home-based commute trips starting in residential areas that have better park access in general.

Table 3.2: Conditional Logit Model Results of Origin Station Choice for Commute Trips

	Model 1			Model 2			Model 3		
Variable	Coeff (SE)	OR	Sig	Coeff (SE)	OR	Sig	Coeff (SE)	OR	Sig
W Walk to Station	-0.559 (0.233)	0.572	**	-0.557 (0.263)	0.573	**	-0.741 (0.120)	0.477	***
R Ratio of walking to trip time	-0.018 (0.037)	0.982		-0.036 (0.045)	0.964				
D Deviation	-0.162 (0.095)	0.850	*	-0.212 (0.107)	0.809	**	-0.201 (0.100)	0.818	**
T Trail within 400m				0.267 (0.550)	1.306				
P Distance to Park				-0.411 (0.198)	0.663	**	-0.417 (0.185)	0.659	**
V Crime (outside CBD)				-0.007 (0.004)	0.993	*	-0.006 (0.003)	0.994	**
M Median Income				-0.013 (0.015)	0.987				
N Chosen (Choices)			97 (485)			97 (485)			97 (485)
McFadden's Pseudo-R^2			0.724			0.758			0.751
BIC			104.730			118.894			102.500

$***$ Significant at $p < 0.01$

$**$ Significant at $p < 0.05$

$*$ Significant at $p < 0.1$

Table 3.3: Conditional Logit Model Results of Origin Station Choice for Non-work Trips

	Model 1			Model 2			Model 3		
Variable	Coeff (SE)	OR	Sig	Coeff (SE)	OR	Sig	Coeff (SE)	OR	Sig
W Walk to Station	-0.117 (0.089)	0.890		-0.113 (0.092)	0.893				
R Ratio of walking to trip time	-0.083 (0.017)	0.920	***	-0.089 (0.018)	0.915	***	-0.108 (0.008)	0.897	***
D Deviation	-0.303 (0.046)	0.738	***	-0.296 (0.047)	0.744	***	-0.327 (0.042)	0.721	***
T Trail within 400m				0.129 (0.272)	1.138				
P Distance to Park				-0.118 (0.082)	0.888				
V Crime (outside CBD)				-0.003 (0.002)	0.997	**	-0.003 (0.002)	0.997	**
M Median Income				-0.011 (0.007)	0.989	*	-0.013 (0.007)	0.988	*
N Chosen (Choices)	394 (1,970)			394 (1,970)			394 (1,970)		
McFadden's Pseudo-R^2	0.700			0.708			0.705		
BIC	402.622			423.060			404.387		

$***$ Significant at $p < 0.01$
$**$ Significant at $p < 0.05$
$*$ Significant at $p < 0.1$

3.2.3 Non-work Trips

Like commute trips, deviation from the shortest path and crime rates for stations outside the CBD are significant. For non-work trips, however, the relative amount of walk time seems to be more important than an absolute threshold of minutes. People making non-work trips prefer to spend most of their travel time on the bicycle rather than walking to the station. A station for which the walk segment comprises a 1-percentage point larger share of the total trip time is only 89.7% as likely to be chosen.

The negative sign on the income variable is curious. Given the demographics of Nice Ride users - higher income, highly educated, young professionals - one would expect stations in higher income neighborhoods to have a higher utility. However, this suggests that a marginal increase in the income level of the neighborhood actually decreases the likelihood for stations within that neighborhood. This could be a function of where Nice Ride subscribers tend to live. Although their demographic profile suggests higher income, they may be more likely to live in diverse neighborhoods than exclusively wealthy areas, so stations in these areas would get more use.

A station with an increase of one violent crime per 10,000 people has a subtle disadvantage (99.7% as likely to be chosen), but rescaling the variable makes the effect more noticeable. A station in a neighborhood with 64 more violent crimes per 10,000 people (the standard deviation of crime rate in this sample) has an odds ratio of 81.9%.

Chapter 4

Conclusions

4.1 Implications for Policy

The findings from this study will be important for practitioners considering or already managing bike-share systems.

4.1.1 Spatial relative advantage

By comparing bike-share to walking accessibility, this study also demonstrated the use of walking as a baseline to show how bike-share improves accessibility. Access to jobs via bike-share and walking vary both spatially and temporally, so this study identified where and when bike-share has the strongest advantage over walking.

The accessibility maps highlight where Nice Ride creates the strongest relative improvement over walking in accessibility to jobs. At higher time thresholds (30 to 40 minutes), the dark band around the periphery of Downtown Minneapolis shows a zone where bike-share deployment has the highest impact on job accessibility. The accessibility protocol used in this report may be useful for existing and new systems to evaluate how their system serves job access. Naturally, station placement near high concentrations of jobs is important. But bike-share planners and administrators can use accessibility to identify where outside of the CBD to concentrate stations.

In addition to spatial variation and advantage, this study identified temporal variation and advantage for bike-share relative to walking. At short accessibility thresholds, bike-share did not provide improved accessibility over walking, and the system's utility is limited to users starting and ending their trips immediately adjacent to the bike-share stations. However, as the time threshold expands, the speed of the bicycling segment of the trip dominates the walking access portion, and bike-share provides improved accessibility in most places. The ratio of Nice Ride to walking accessibility was below 1.0 at the 5- and 10-minute thresholds, and it was highest at 30 minutes. This information can help planners design a system that connects origins and destinations within this range, without expending resources trying to serve trips that are either too short or too long.

4.1.2 Relative preference for biking over walking

The models for commute trips and non-work trips found preference for shorter walking segments, both in absolute terms (minutes walking to the station), and relative terms (ratio of walk time to overall trip time). The relative value of walking and biking times versus distance can inform decisions about station spacing and network expansion. A strong preference for time spent biking over walking suggests that a denser network may enable people to decrease these walking segments. While spacing stations along a route would enable people to walk in the direction of their destination to pick up a bike, given the preference for time spent biking, clustering stations near where people are starting and ending their trips may make more sense.

The preference for longer biking durations relative to walking suggests that the pricing structure that discourages longer bike trips may be undermining the utility of the system somewhat. In situations where people are faced with a decision about taking a longer trip that is comprised of a larger share of biking time, the typical pricing structure that starts charging trip fees beyond 30 minutes may deter ridership.

4.1.3 How far people walk to access stations

More fundamentally than the tradeoffs between walking and biking time and overall distance, this study helps us learn how far people walk to stations in general. There is no control group of people who didn't make a trip to advise how far is too far, but there is at least evidence that the vast majority of people prefer to use the closest station. With future research, this may help with forecasting or anticipating demand by providing an appropriate catchment area size for each station.

4.1.4 Station Amenities and Neighborhood Attributes

Unlike an aggregate model of station use, such as [8], this study measures how individuals choose which stations to use. The aggregate model estimates the value of station amenities and nearby businesses as trip generators and attractors. But in this study, the station choice is assumed to be to some extent independent of the trip purpose, and only dependent on the origin and destination spatially (with the exception of commute trips or other trip purposes that constrain time). The findings from the regression models in this study identified the disproportionate importance of parks for commute trips. Stations closer to parks were more likely to be chosen, all else equal. The importance of parks for commuters may ease tension within bike-share system administration about planning for regular long-term members versus recreational short-term users who generate more revenue.

4.2 Limitations and Areas for Future Study

This study had several notable limitations. The data came from the Nice Ride Minnesota system, a mid-sized bike-share network with well-managed station balancing efforts. Because network congestion is not an issue here, uncertainty variables such as station capacity and probability of being empty or full when a traveler needs a bicycle were not included. The results from this study will therefore be more applicable to small- and medium-sized cities with a similar operations context. Larger systems that face greater congestion challenges, such as Washington, D.C., may find that the station choice model results are inadequate because they disregard this significant source of uncertainty for users.

4.2.1 Accessibility Type and Strategy

The accessibility calculations focused strictly on job accessibility. A natural next step will be to consider worker accessibility. While mapping job accessibility shows where bike-share has the strongest spatial advantage, overlaying worker accessibility will produce a suitability map that considers where workers live in addition to where jobs are located. Job and worker accessibility are important for daily commuters, but bike-share system planners may also look at accessibility to other destinations, depending on their system goals. Accessibility to parks and grocery stores could be used to guide equity-based system expansions. Accessibility to tourist attractions, hotels, dining, and entertainment may help plan for short term day-pass users, who typically generate greater revenue for the system. Although these accessibility maps show where bike-share has the strongest spatial advantage over walking, an empirical study is needed to evaluate how well these measures predict system use.

4.2.2 Station Choice Modeling

Another limitation is the unit of analysis for neighborhood attribute variables. Crime reports are not available at any level finer than a neighborhood, but this means that many participants' entire choice sets may fall entirely within a single neighborhood, so that all the nearby stations have the same measure of crime rate. Median income was evaluated at the same level as crime rate for consistency, but is available at smaller levels of aggregation. Future analysis might consider removing the crime variable, measuring income levels at the block group or census tract level, and adding other neighborhood spatial variables.

This paper set up a framework for evaluating route choice in bike-share trips. The empirical model focused strictly on the station access component, but future research should consider the egress segment and the bicycling route as well. Some of the examples from transit literature, such as [1], provide a starting point for jointly estimating these components.

References

[1] Bovy, P.H.L. and Hoogendoorn-Lanser, S. (2005). "Modelling route choice behaviour in multi-modal transport networks." *Transportation*, 32(4): 341–368. doi:10.1007/s11116-004-7963-2.

[2] Chalermpong, S. and Wibowo, S.S. (2007). "Transit Station Access Trips and Factors Affecting Propensity to Walk to Transit Stations in Bangkok, Thailand." *Journal of the Eastern Asia Society for Transportation Studies*, 7: 1806–1819.

[3] Guo, Z. (2009). "Does the pedestrian environment affect the utility of walking? A case of path choice in downtown Boston." *Transportation Research Part D: Transport and the Environment*, 14(5): 343–352. doi:10.1016/j.trd.2009.03.007.

[4] Guo, Z. (2011). "Mind the map! The impact of transit maps on path choice in public transit." *Transportation Research Part A: Policy and Practice*, 45(7): 625–639. doi:10.1016/j.tra.2011.04.001.

[5] Hsiao, S., Lu, J., Sterling, J., and Weatherford, M. (1997). "Use of Geographic Information System for Analysis of Transit Pedestrian Access." *Transportation Research Record*, 1604: 50–59.

[6] McFadden, D.L. (1974). "Conditional logit analysis of qualitative choice behavior." In P. Zarembka, editor, *Frontiers in Econometrics*, chapter 4, pages 105–142. Academic Press, New York.

[7] Owen, A. (2013). *Modeling the Commute Mode Share of Transit Using Continuous Accessibility to Jobs*. Masters thesis, University of Minnesota, Minneapolis.

[8] Schoner, J.E., Harrison, R.A., Wang, X., and Lindsey, G. (2012). *Sharing to Grow: Economic Activity Associated with Nice Ride Bike Share Stations*. Technical Report September, University of Minnesota and Bikes Belong Foundation, Minneapolis.

[9] Wang, X., Lindsey, G., Schoner, J.E., and Harrison, R.A. (2013). "Modeling Bike Share Station Activity: The Effects of Nearby Businesses and Jobs on Trips To and From Stations." In *Transportation Research Board 92nd Annual Meeting Compendium of Papers*. Washington, D.C.

[10] Wardman, M. (2004). "Public transport values of time." *Transport Policy*, 11(4): 363–377. doi:10.1016/j.tranpol.2004.05.001.

Appendix A Accessibility Maps

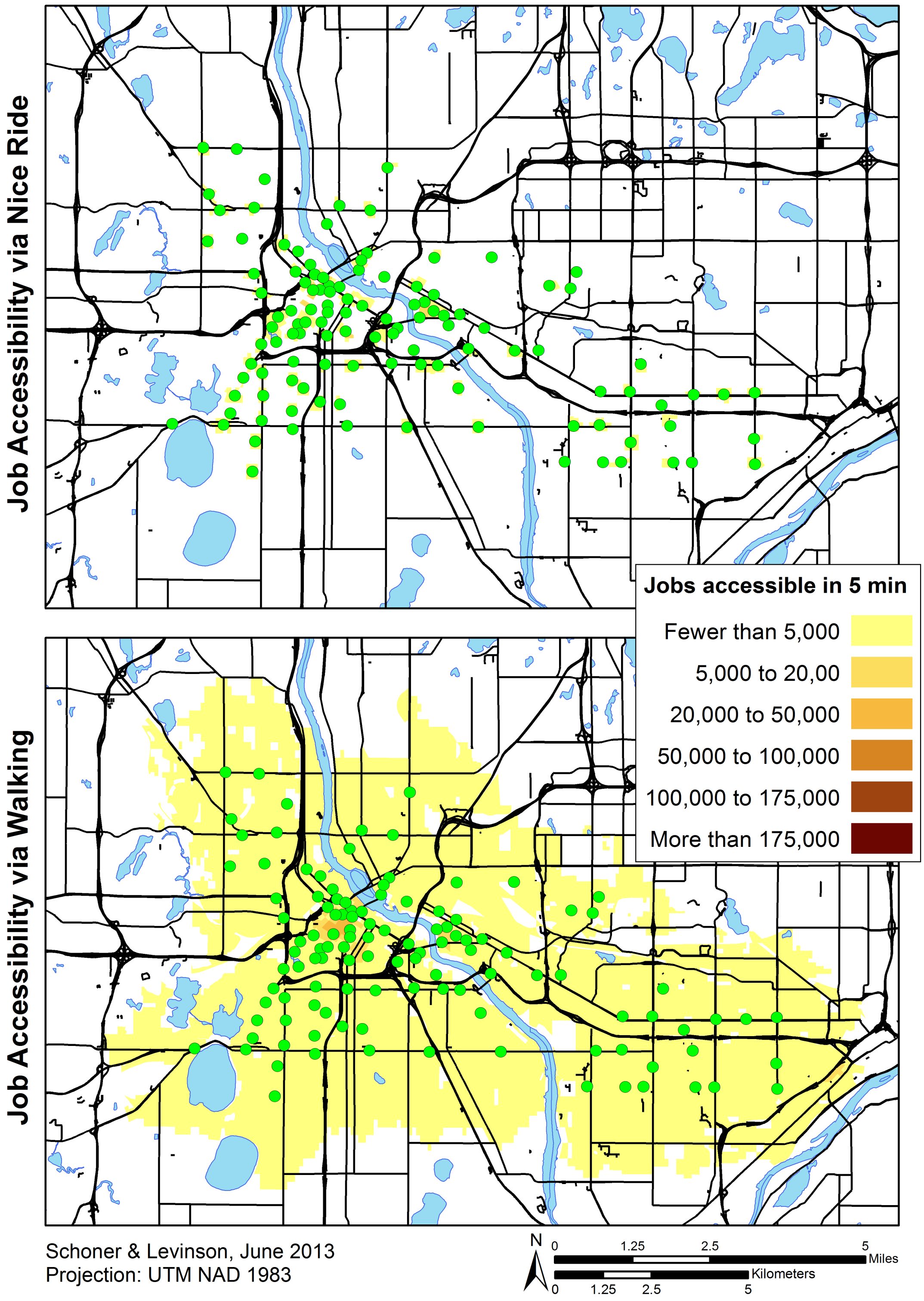

Figure A.1: 5 Minute Job Accessibility by Nice Ride and Walking

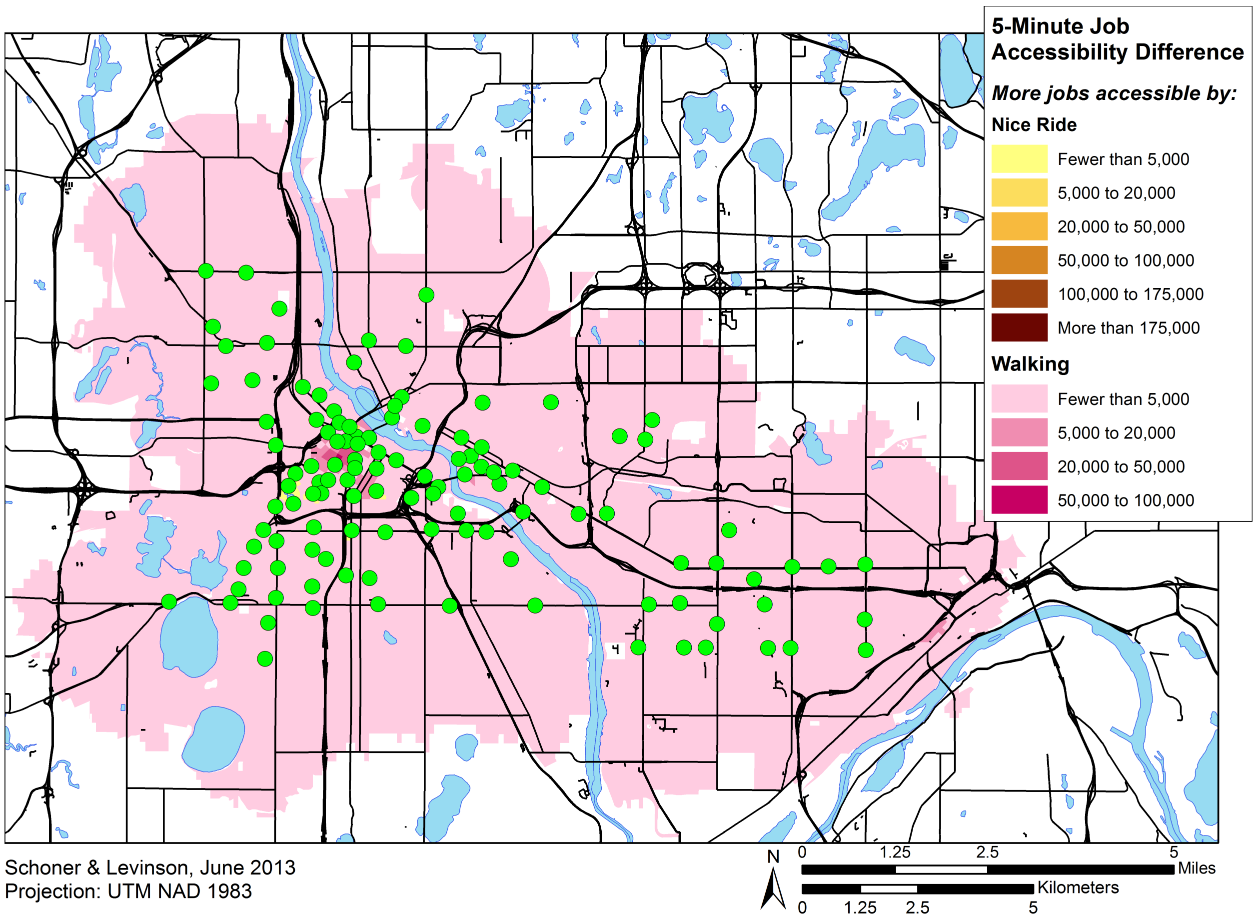

Figure A.2: 5 Minute Job Accessibility Difference between Nice Ride and Walking

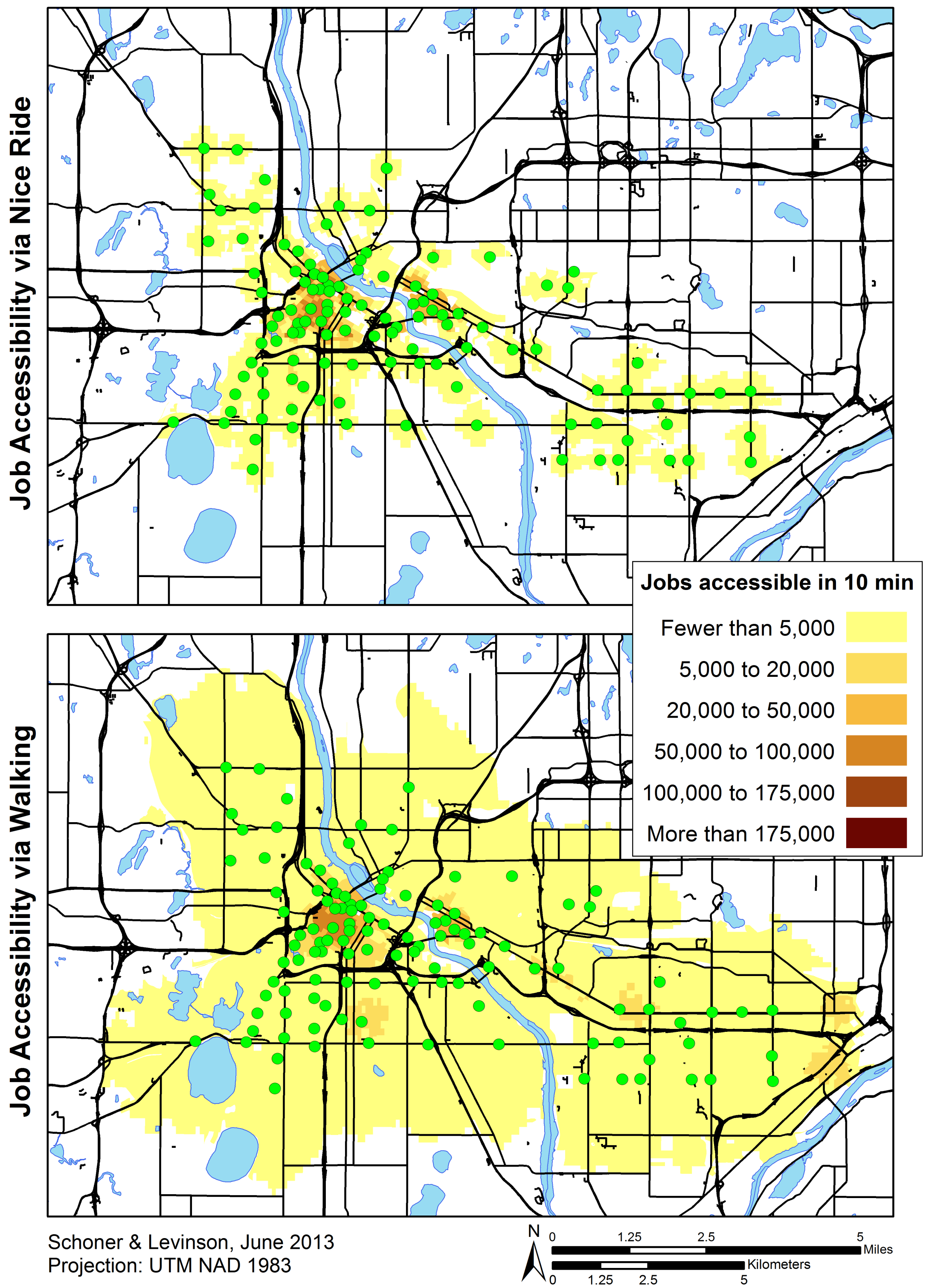

Figure A.3: 10 Minute Job Accessibility by Nice Ride and Walking

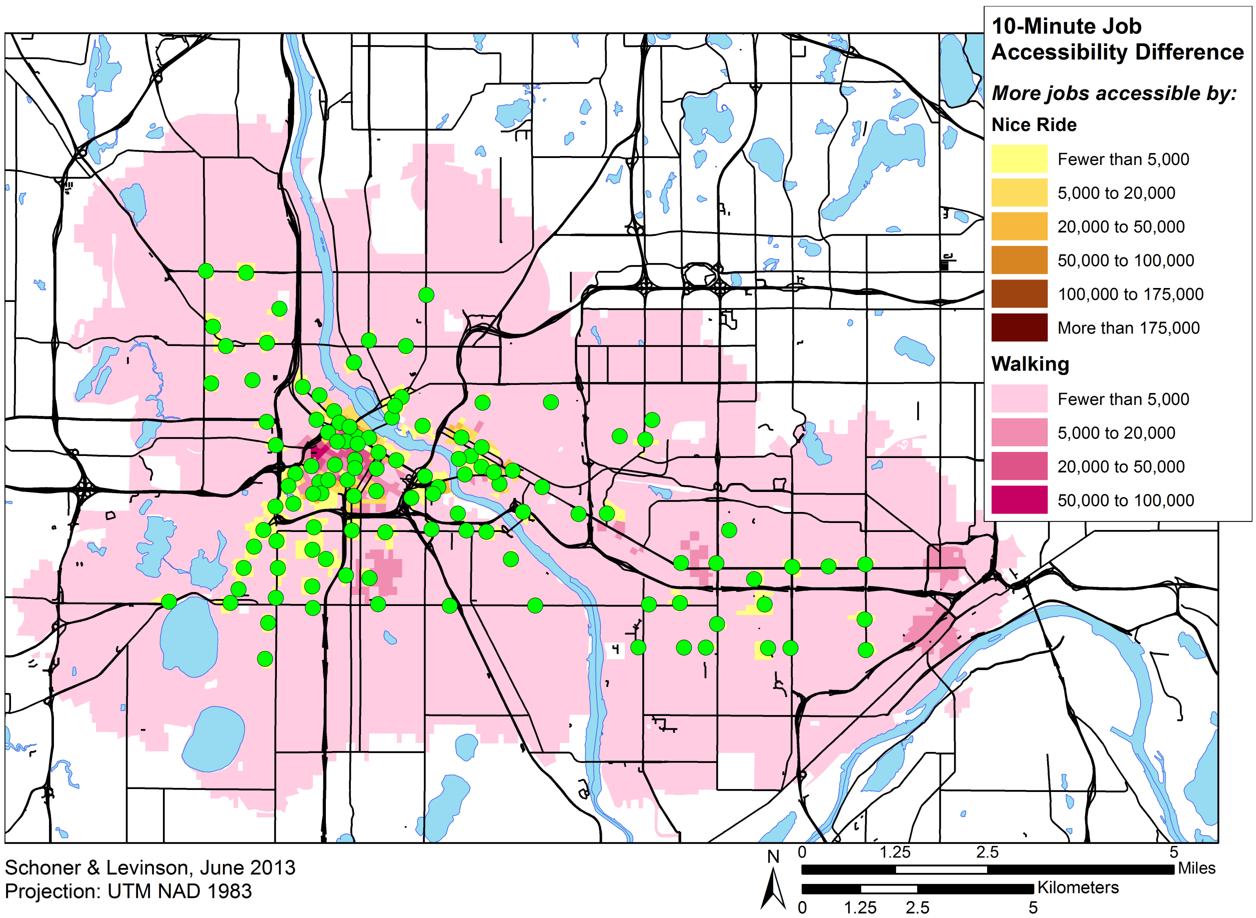

Figure A.4: 10 Minute Job Accessibility Difference between Nice Ride and Walking

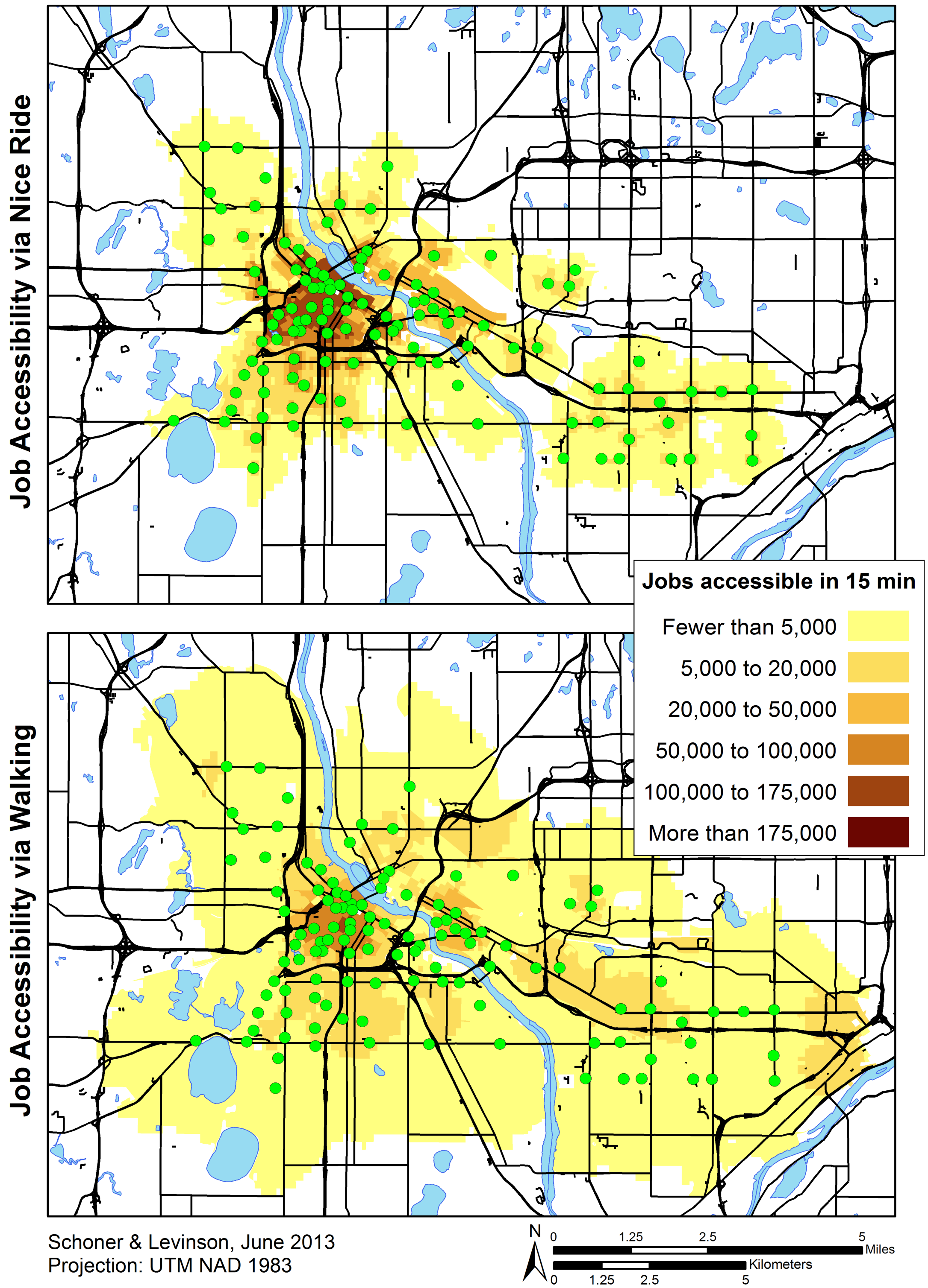

Figure A.5: 15 Minute Job Accessibility by Nice Ride and Walking

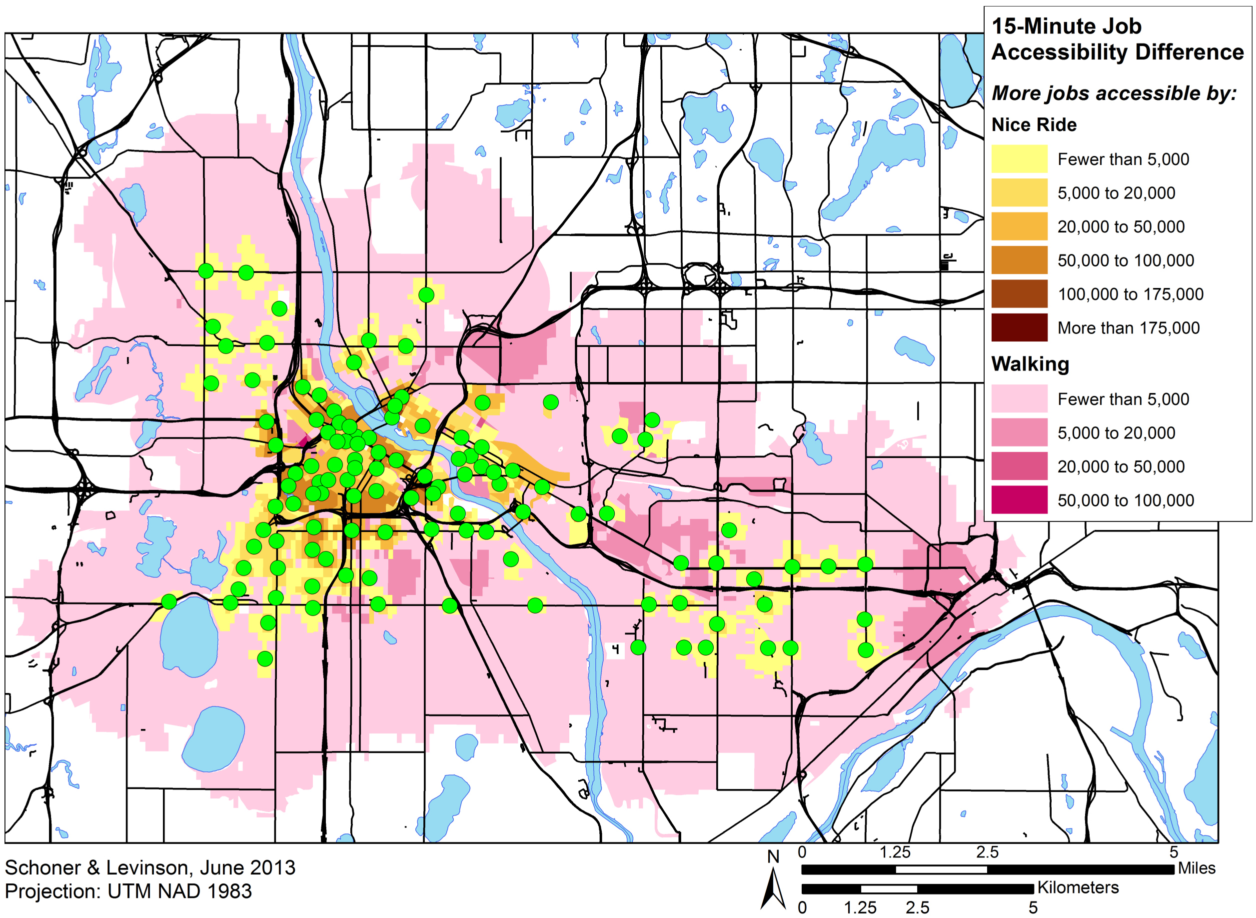

Figure A.6: 15 Minute Job Accessibility Difference between Nice Ride and Walking

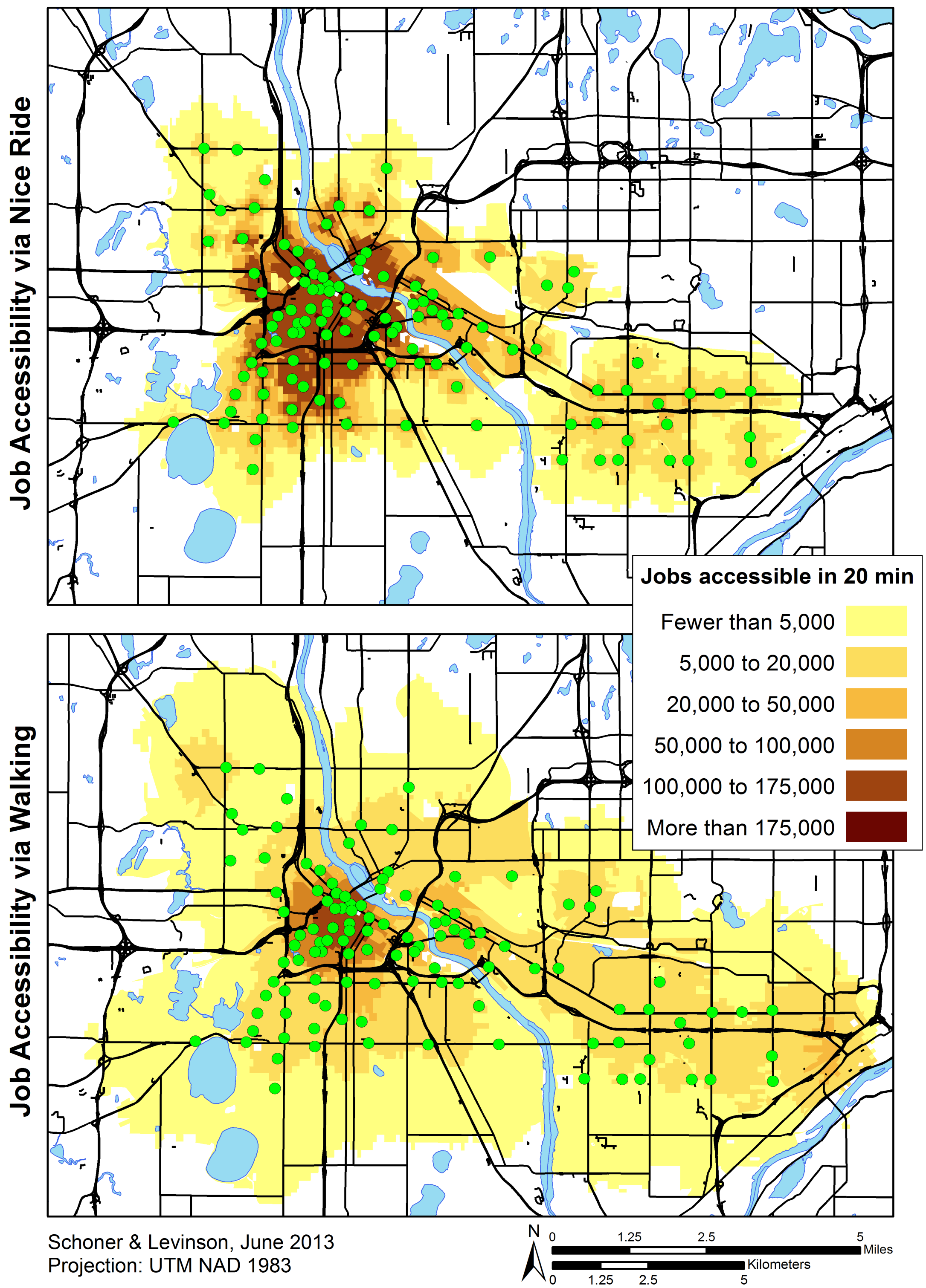

Figure A.7: 20 Minute Job Accessibility by Nice Ride and Walking

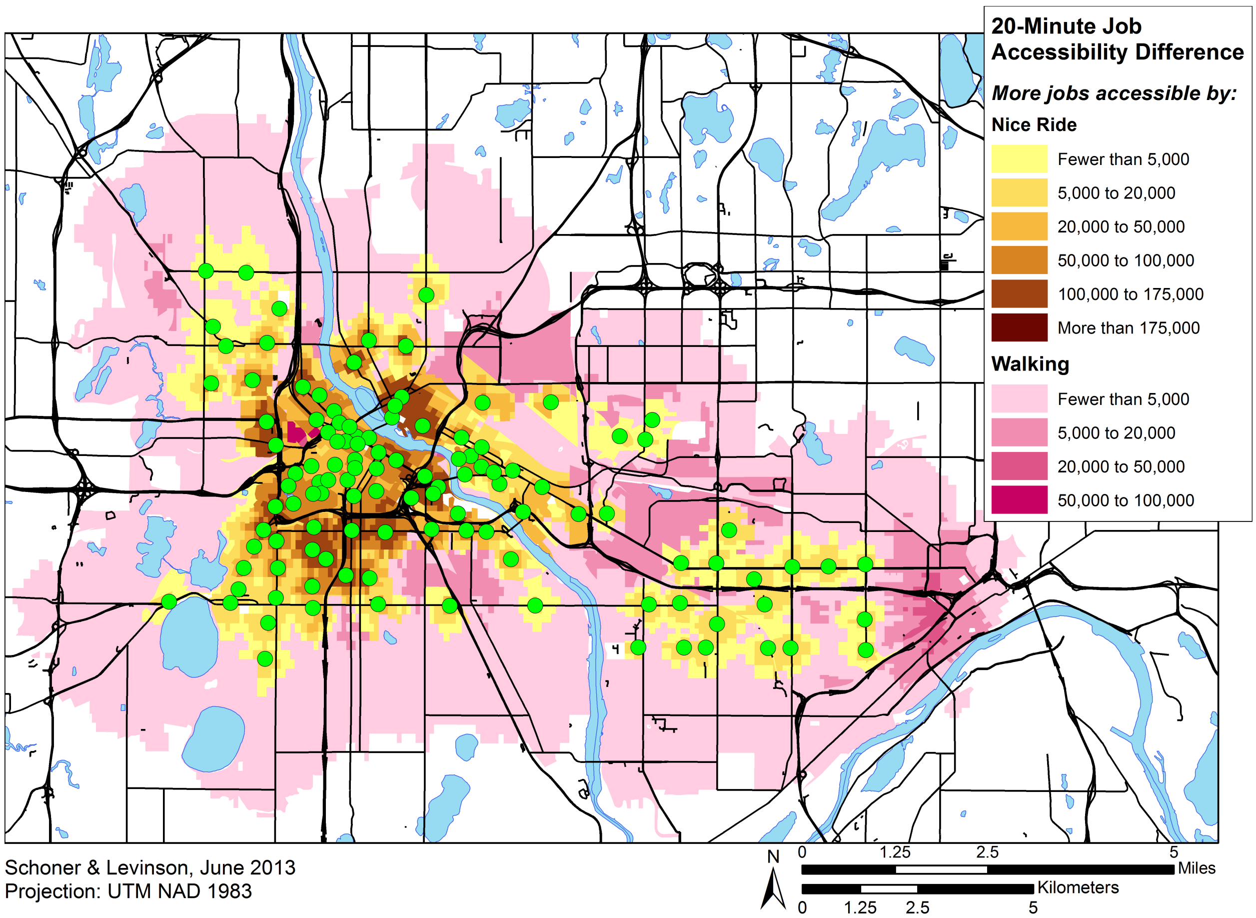

Figure A.8: 20 Minute Job Accessibility Difference between Nice Ride and Walking

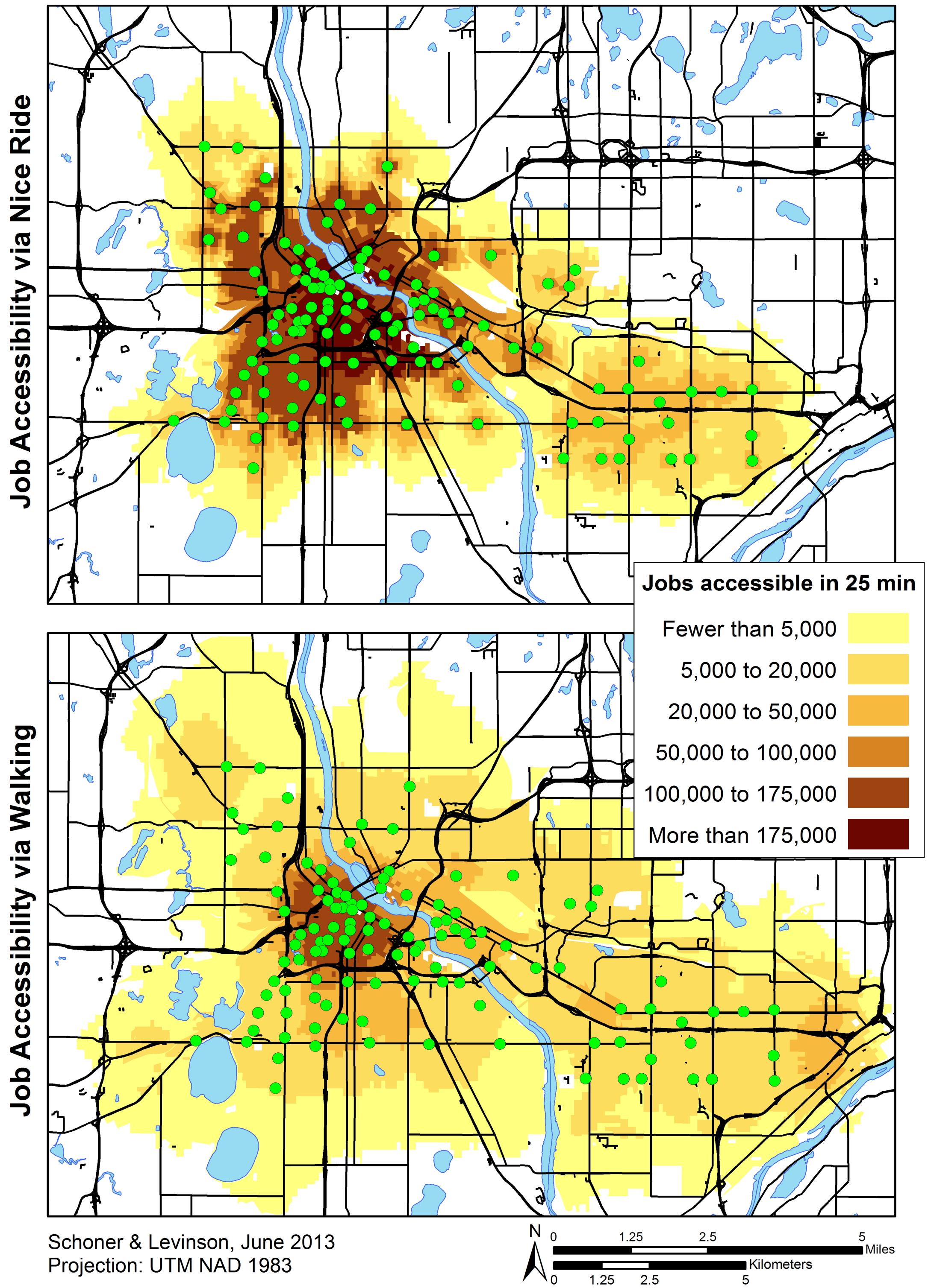

Figure A.9: 25 Minute Job Accessibility by Nice Ride and Walking

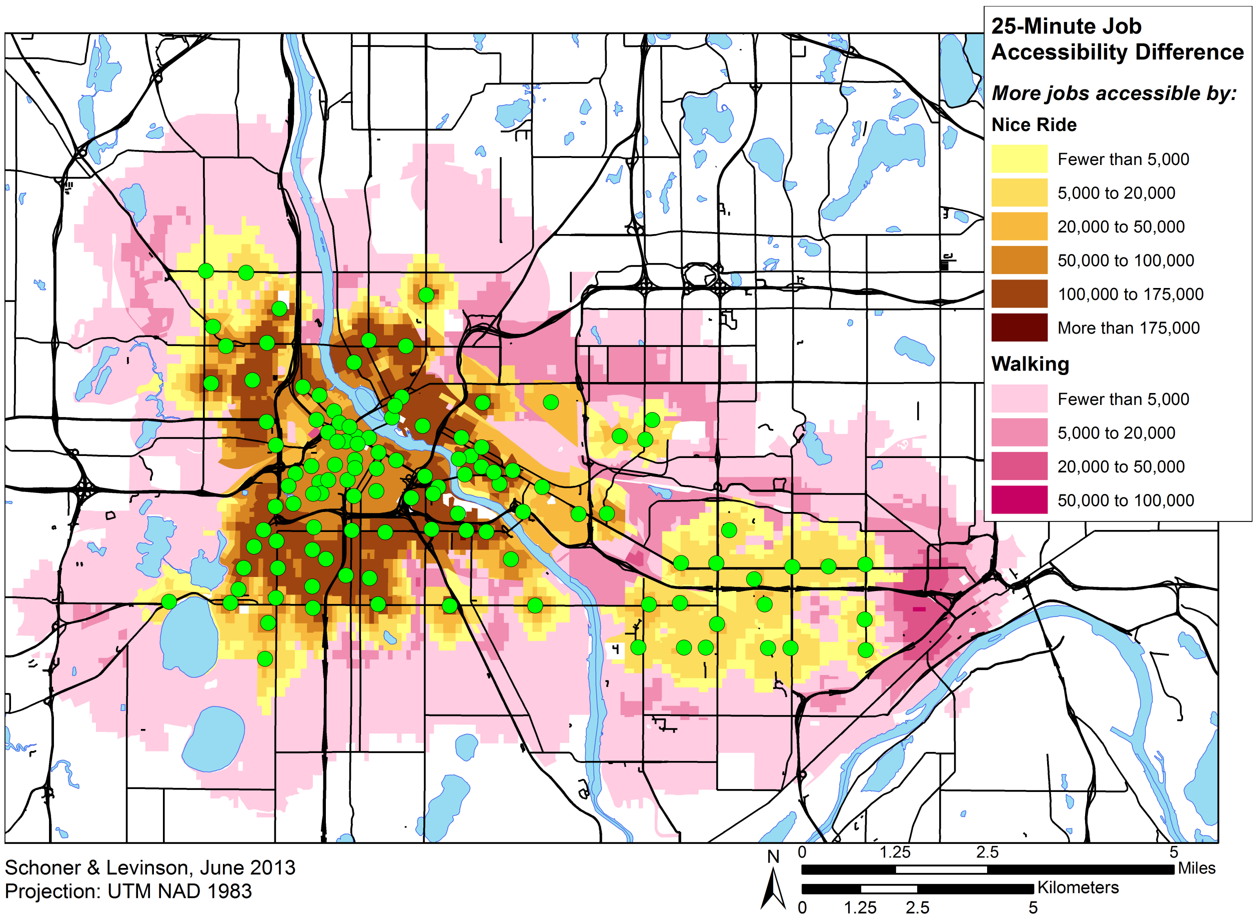

Figure A.10: 25 Minute Job Accessibility Difference between Nice Ride and Walking

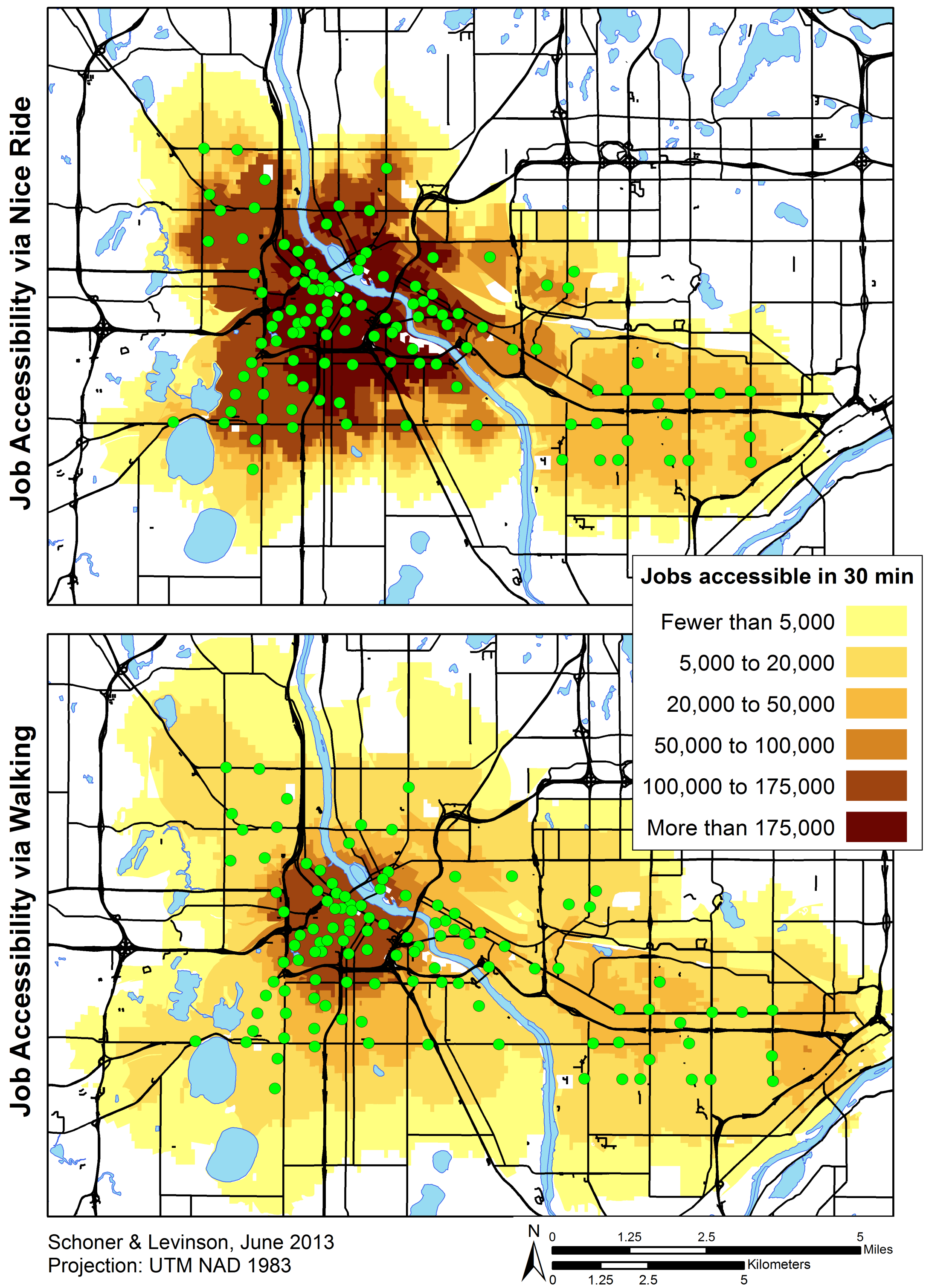

Figure A.11: 30 Minute Job Accessibility by Nice Ride and Walking

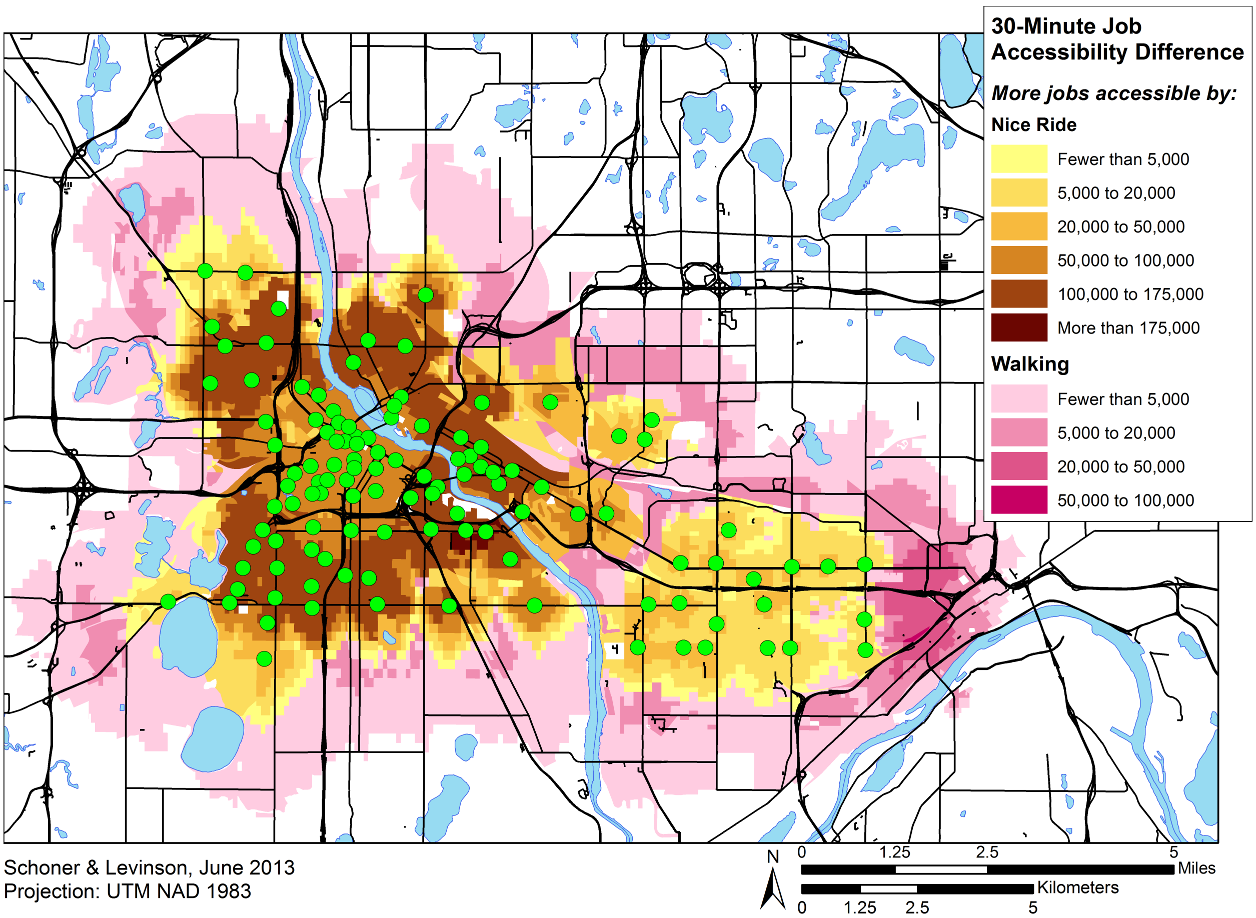

Figure A.12: 30 Minute Job Accessibility Difference between Nice Ride and Walking

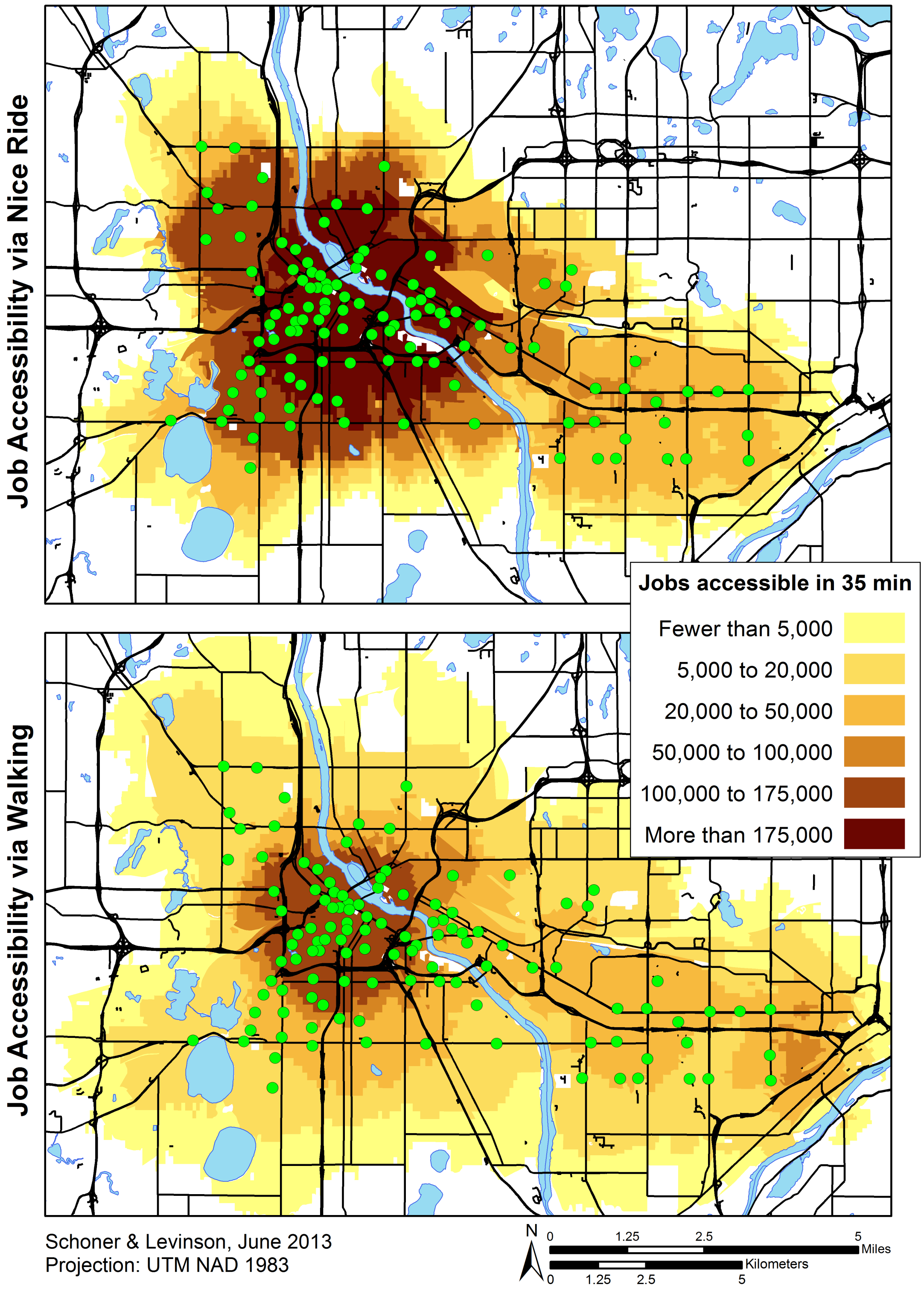

Figure A.13: 35 Minute Job Accessibility by Nice Ride and Walking

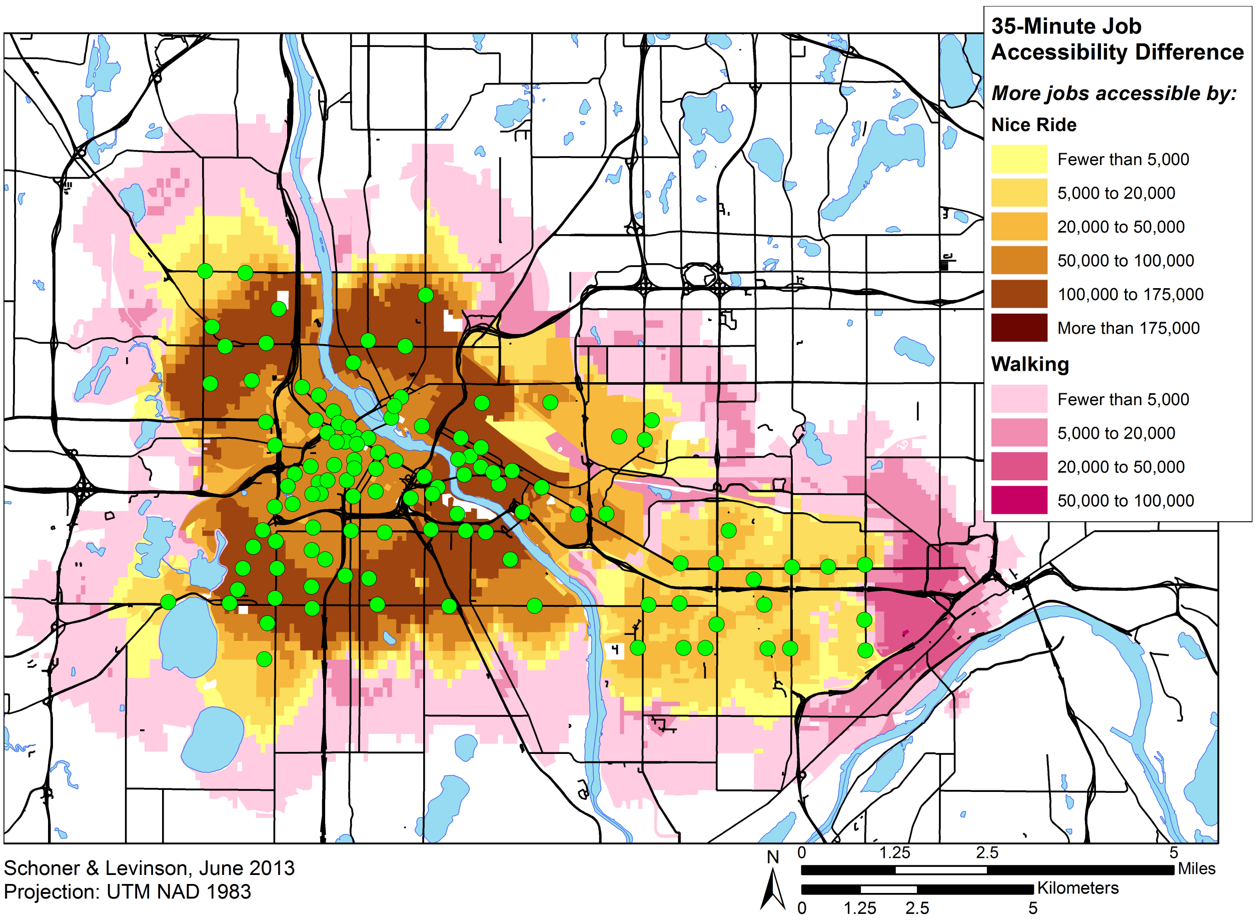

Figure A.14: 35 Minute Job Accessibility Difference between Nice Ride and Walking

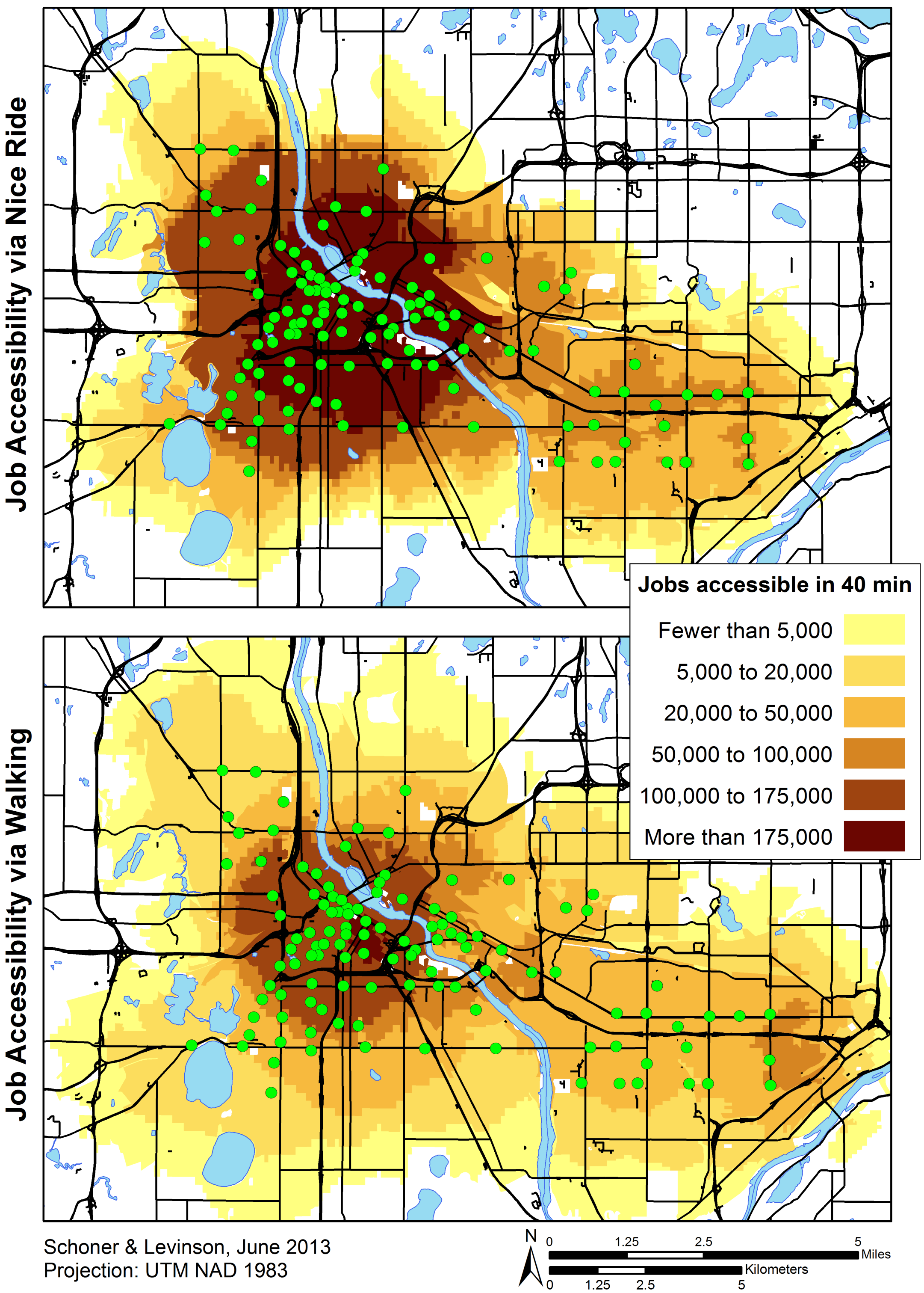

Figure A.15: 40 Minute Job Accessibility by Nice Ride and Walking

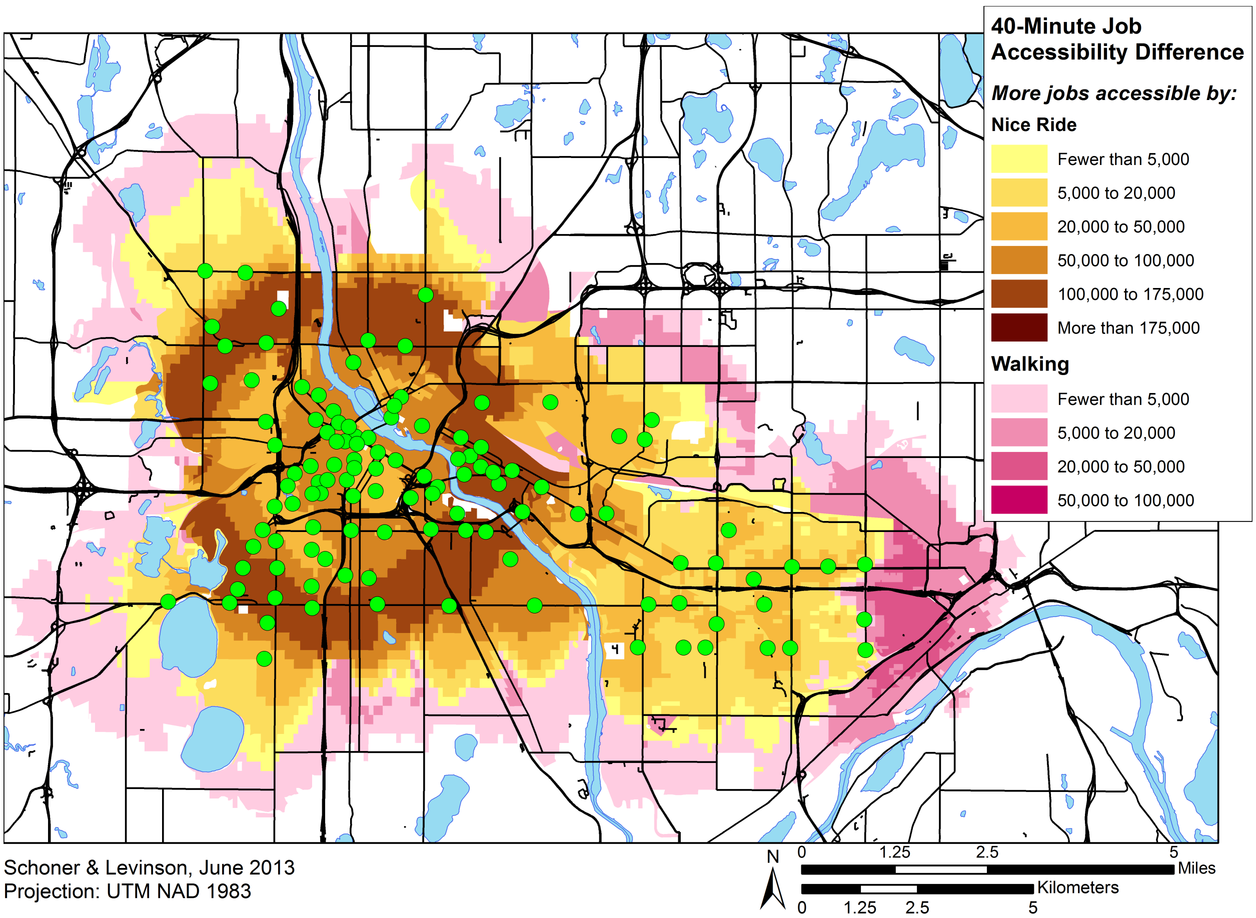

Figure A.16: 40 Minute Job Accessibility Difference between Nice Ride and Walking

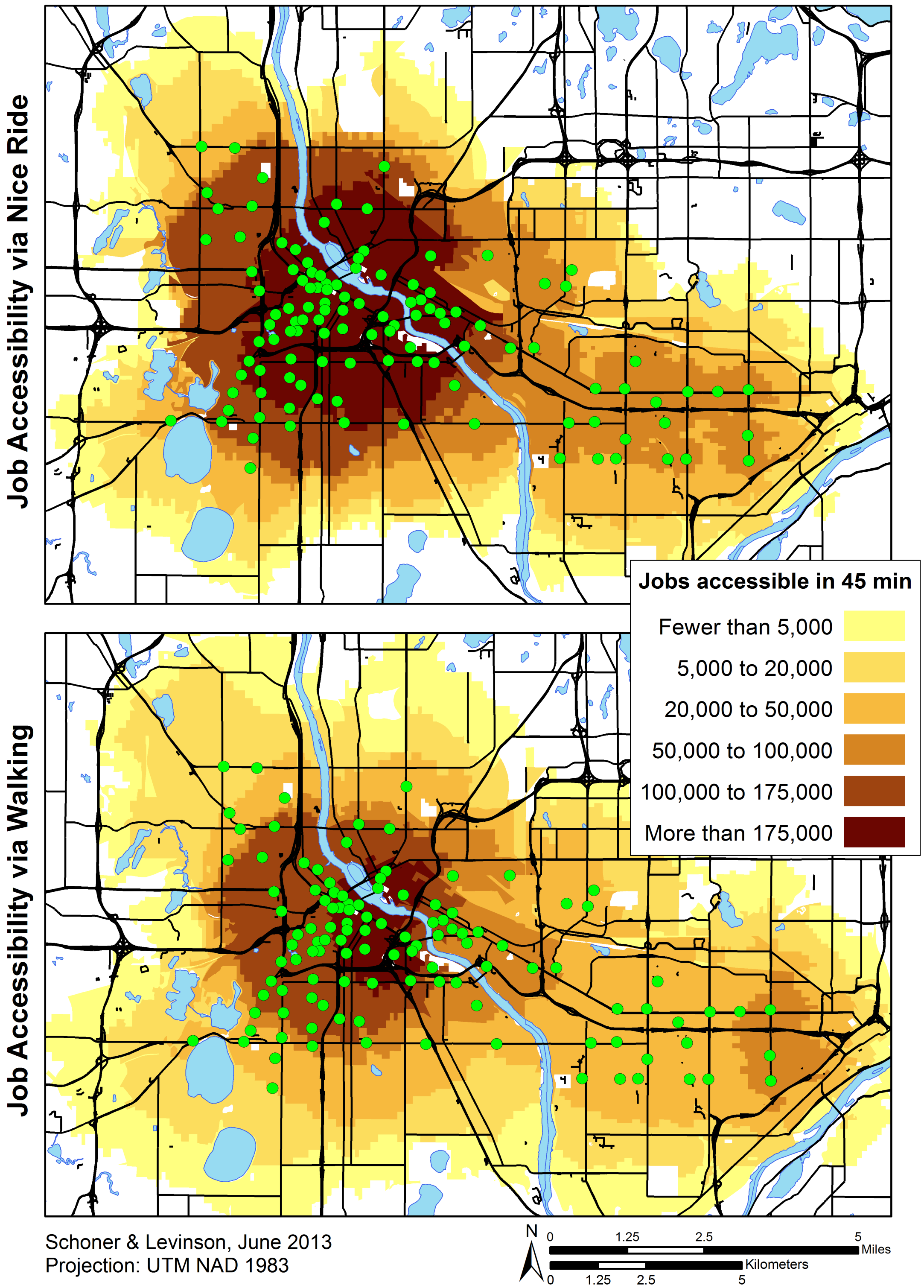

Figure A.17: 45 Minute Job Accessibility by Nice Ride and Walking

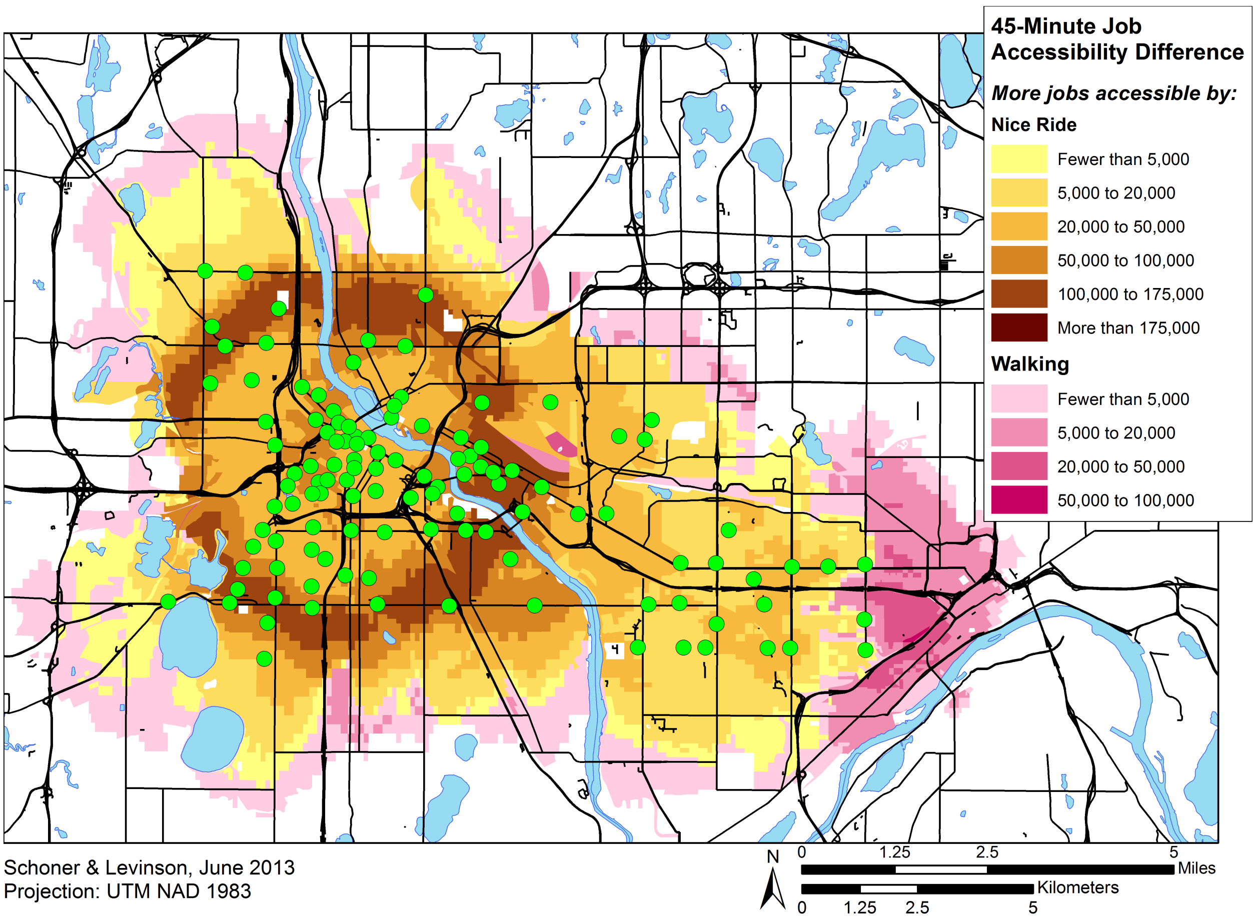

Figure A.18: 45 Minute Job Accessibility Difference between Nice Ride and Walking

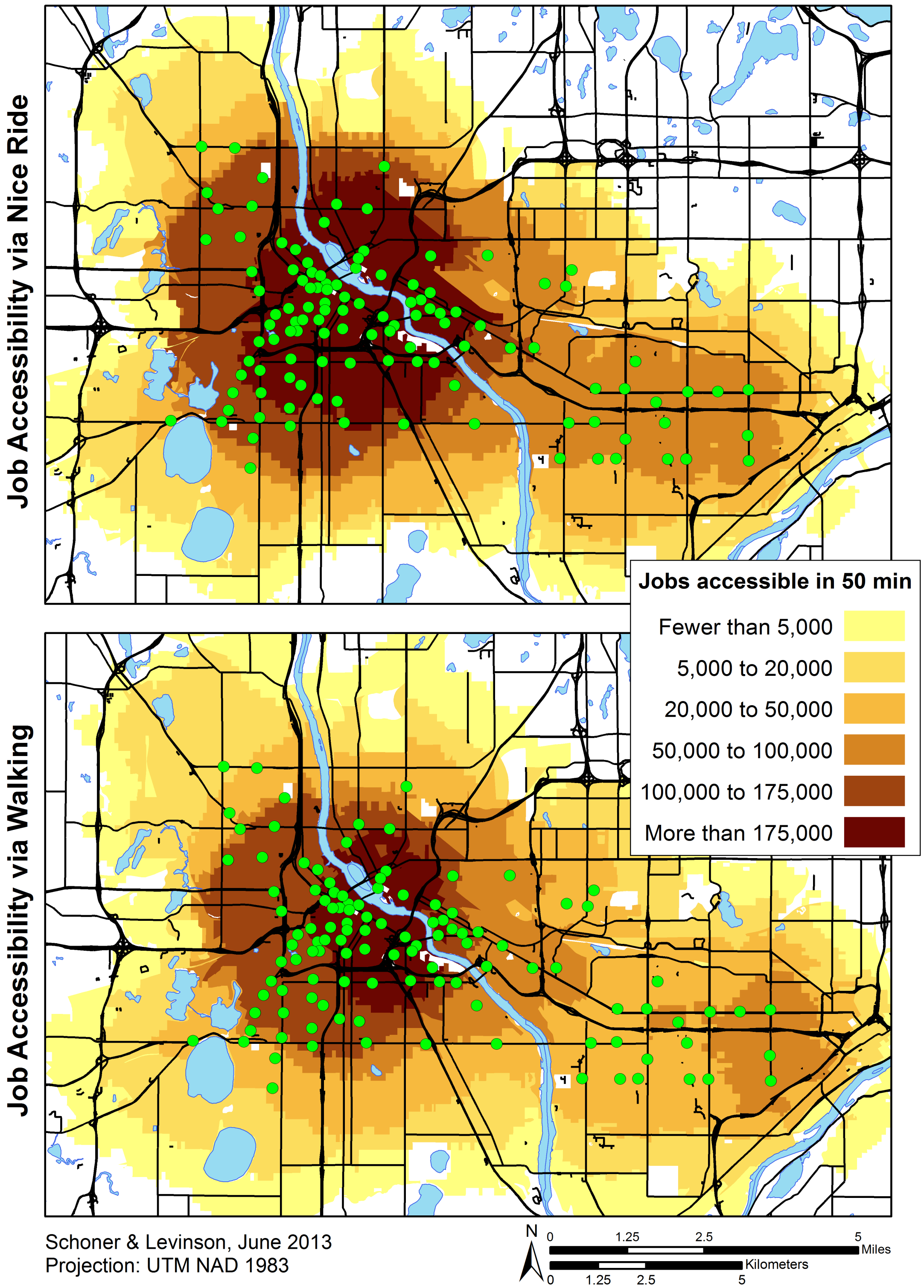

Figure A.19: 50 Minute Job Accessibility by Nice Ride and Walking

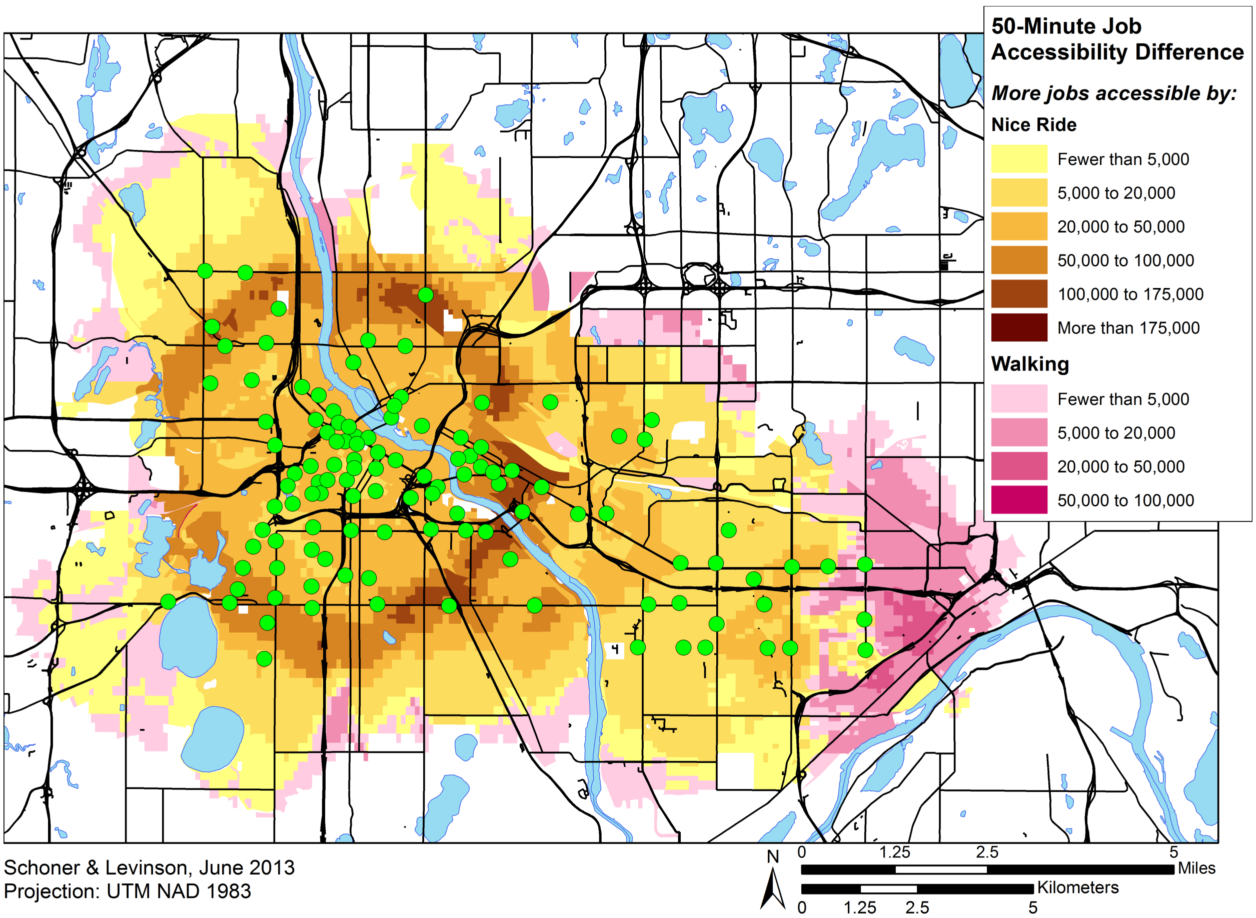

Figure A.20: 50 Minute Job Accessibility Difference between Nice Ride and Walking

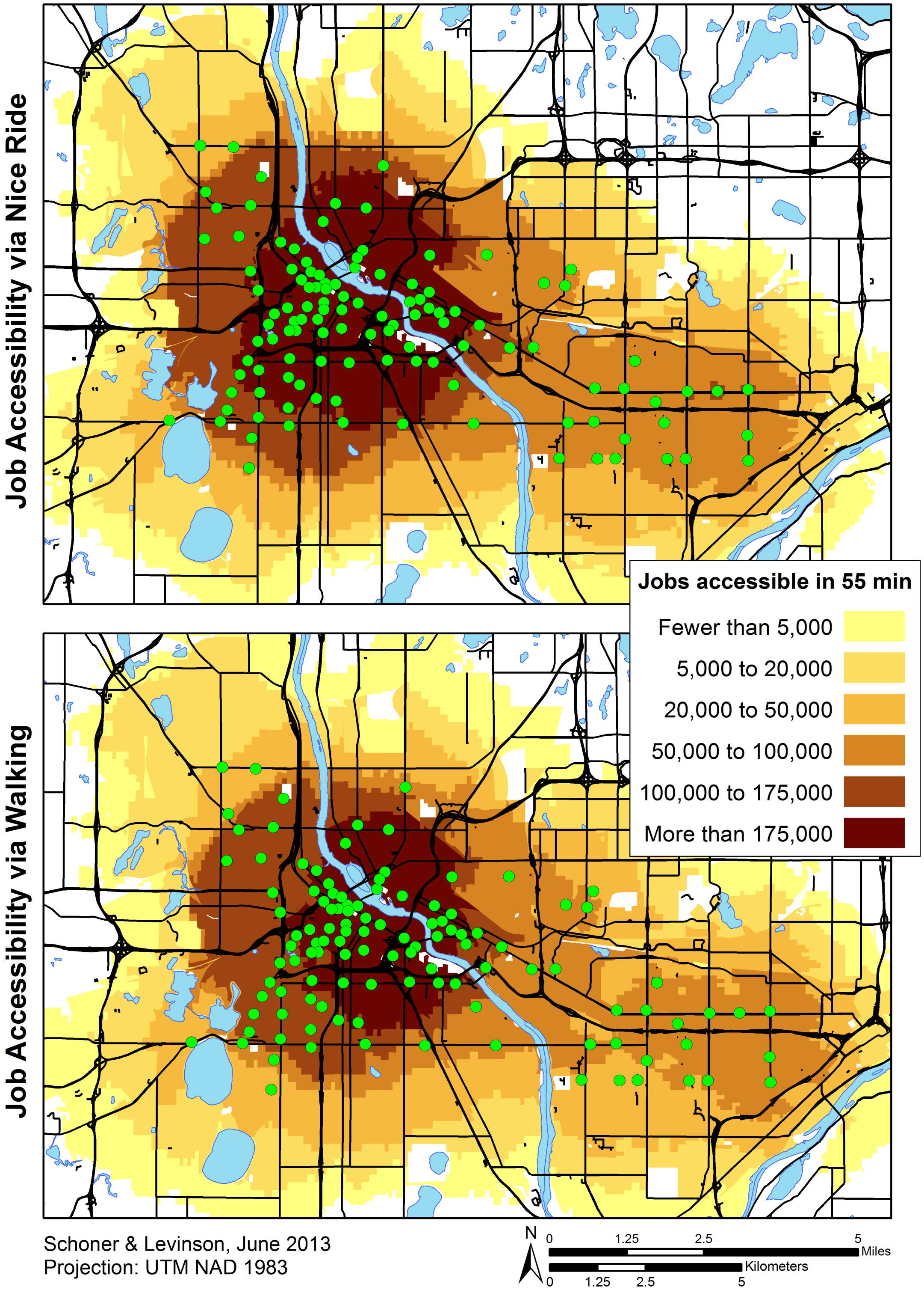

Figure A.21: 55 Minute Job Accessibility by Nice Ride and Walking

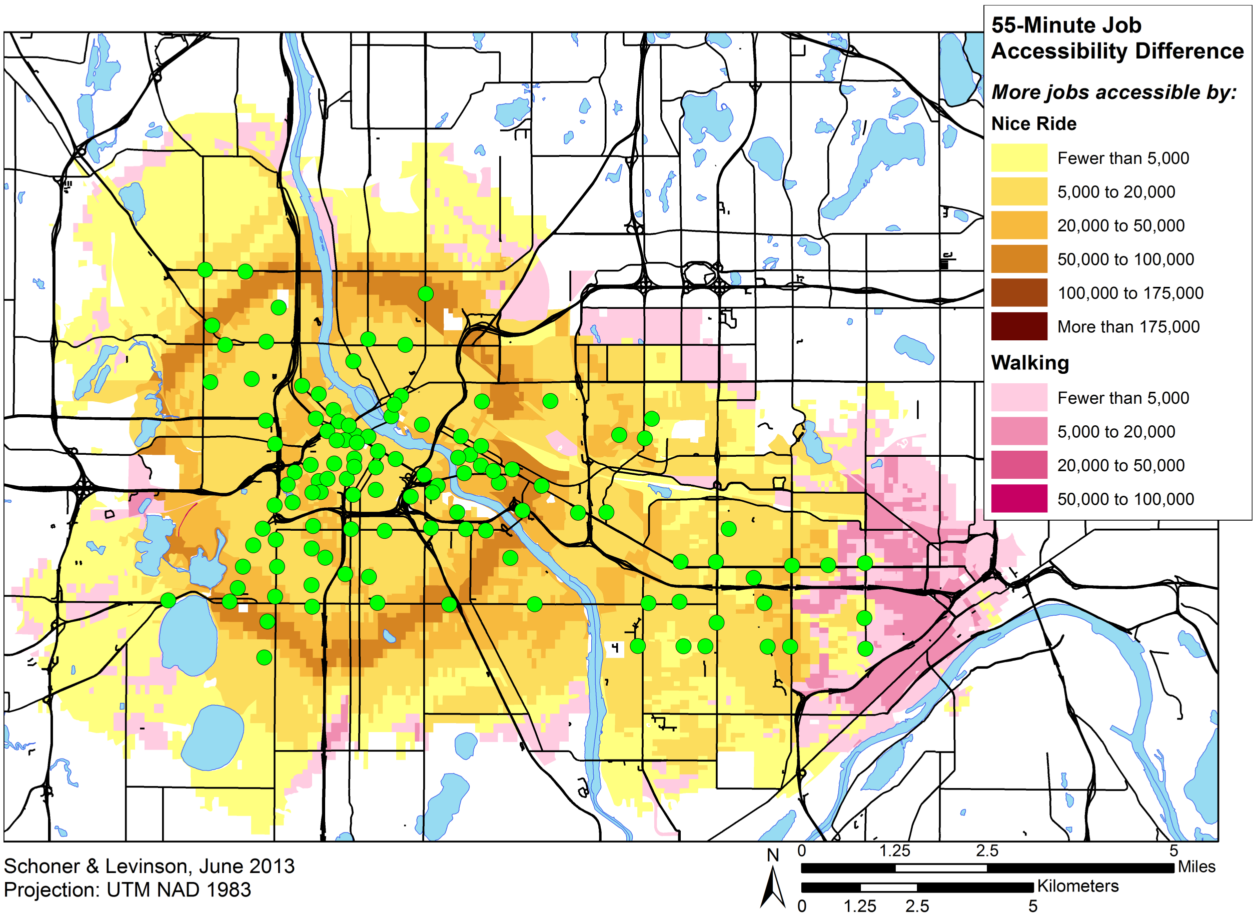

Figure A.22: 55 Minute Job Accessibility Difference between Nice Ride and Walking