Access Across America: Bike 2021 Methodology

Prepared by the

Accessibility Observatory at the University of Minnesota

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ACCESSIBILITY OBSERVATORY

UNIVERSITY OF MINNESOTA

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Contents

1 Summary

This document describes the methodology used by the Accessibility Observatory at the University of Minnesota to produce the accessibility metrics and related data that are presented in *Access Across America: Bike 2021*. An overview of the methodology for the Observatory's 2021 reports and calculations is provided below, and detailed descriptions can be found in the following sections.

- **Data Sources**
  1. U.S. Census TIGER 2010 datasets: blocks, core-based statistical areas (CBSAs)
  2. U.S. Census Longitudinal Employer-Household Dynamics (LEHD) 2019 Origin-Destination Employment Statistics (LODES)
  3. OpenStreetMap (OSM) North America extracts, retrieved January 1, 2021 and January 14, 2020.
- **Data Preparation**
  1. Divide the geographical United States into analysis zones for efficient parallelization
  2. Construct unified pedestrian-bicycle network graph for each analysis zone
  3. Assign Level of Traffic Stress (LTS) scores to each street link and intersection across the United States
- **Accessibility Calculation**
  1. For each Census block in the United States, calculate travel time to all other blocks within 20km, at a single departure time of noon
  2. Calculate cumulative opportunity accessibility to jobs for each block and LTS score, using thresholds of 5, 10, 15, …, 60 minutes
  3. Average accessibility for each included CBSA over all blocks, weighting by number of workers in each block
  4. Calculate weighted ranking for each included metropolitan area, at each LTS level

2 Data Sources

2.1 Geography

All calculations and results in this project are based on geographies defined by the U.S. Census Bureau. Census blocks are the fundamental unit for on-network travel time calculation, and calculations are performed for every census block (excluding blocks that contain no land area) in the United States. Block-level accessibility results are then aggregated across core-based statistical areas (CBSAs) for metropolitan-level analysis. These geography definitions are provided by the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) program.[1] This project uses the geography definitions established for the 2010 decennial census.

2.2 Employment and Worker Population

Data describing the distribution of labor and employment in the region are drawn from the U.S. Census Bureau's Longitudinal Employer-Household Dynamics program (LEHD).[2] The LEHD Origin-Destination Employment Statistics (LODES) dataset, which is updated annually, provides Census block-level estimates of employee home and work locations. This project uses LODES data from 2019, the most recent available as of the performance of the 2021 accessibility calculations.

Note: The LODES dataset used in this report does not include job location data from the states of Alaska, Arkansas, or Mississippi. These states did not report these employment statistics to the Census for the 2019 year.[3] None of the top 50 metropolitan statistical areas reported in the *Access Across America: Bike 2021* lie within those states; however, Memphis (49th by total employment) borders both Arkansas and Mississippi, and thus access to jobs from areas within Memphis is likely to be underreported given the absence of those nearby job locations in the dataset.

2.3 Bicycle Network

Data describing the bicycle network across the country were obtained from OpenStreetMap,[4] an open-access online database of transportation network structures, maps, and other spatial information. OpenStreetMap, like Wikipedia, is composed of contributions from many individuals. In urban areas, it typically provides a much more detailed and up-to-date representation of pedestrian and bicycle networks than datasets available from federal, state, regional, or local sources. The data used in this project were retrieved from OpenStreetMap on January 1, 2021 (for the 2021 calculations) and on January 14, 2020 (for the 2020 calculations). Specifically, the bicycle network is composed of all roadway features that are not restricted-access (e.g. interstate highways) as well as all separated facilities and off-street paths on which bicycles are permitted; the pedestrian network is composed of features with the "footway," "pedestrian," and "residential" tags. The bicycle network elements include OpenStreetMap tag

[1] https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

[2] http://lehd.ces.census.gov/data/

[3] a detailed LODES data release notes is here: https://lehd.ces.census.gov/data/lodes/LODES8/LODESTechDoc8.0.pdf

[4] http://openstreetmap.org

data, which describe attributes such as the presence of bike lanes; these tag data are used in the LTS assignment procedure described in the following section.

3 Data Preparation

3.1 Level of Traffic Stress Assignment

Level of Traffic Stress (LTS) is a metric used to evaluate how "stressful" a given street is to bike on, based on physical attributes of the roadway and bicycle facilities, if any. LTS evaluation is outlined in Mekuria et al. (2012); Furth et al. (2016), and identified as a data-driven performance metric in Cesme et al. (2017). The LTS process ingests a variety of roadway characteristics, such as the presence or absence of bike facilities, numbers of lanes, and roadway speeds, and assigns a value of 1 (lowest stress) to 4 (highest stress) to street segments based on these characteristics.

In order to calculate access to destinations by bicycle, on low-stress bicycle routes, the low-stress facilities must first be identified. The bicycle LTS assignment heuristics employed in this study consist of a set of hierarchical classification rules that assign bicycle LTS ranks to both street segments and intersections, based upon OSM tag data. Table 1 below outlines the classification rules for street segments, and Table 2 gives the signalization rules for intersections. In general, the rules are applied in order of decreasing specificity, and are listed in such an order.

Limited-access roadways that disallow bicycles, such as interstates, are not considered for routing; only street segments where bicycles are either expressly permitted, or not disallowed, are considered for the LTS ranking process. Information regarding the type of bicycle amenity implemented is first used, such as the presence of a protected bike lane. As information regarding bicycle amenities, lane numbers, and roadway speeds does not exist for some roadway segments in the OSM database, hierarchical classification of roadways as "primary," "secondary," and "tertiary" is used later in the LTS assignment process as a proxy for physical roadway design characteristics which influence LTS rank.

A dummy category of "LTS 5" is used in the special cases of motorways, motorway links, and the rare case of raceways—these ways should never be routable for bicycles unless explicitly designated, but if another roadway crosses one with a signal, crossing should be allowed at stress factor of the crossing roadway. If there is no signalization, then the "LTS 5" label disallows crossing in all bicycle routing cases.

Intersections are handled in such a way that their LTS rank is dependent upon the LTS ranks of their approaching roadway segments. If an intersection is controlled by traffic signal devices, the LTS rank of the intersection is set to the lowest-stress rank of all approaching roadways; if an intersection is uncontrolled, the LTS rank of the intersection is set to the highest-stress rank of all approaching roadways. This approach acknowledges the importance of complete routing when considering bicycle traffic—that is, a single stressful intersection crossing along an otherwise low-stress route may deter riders from using the facilities.

Intersections are coded in a few different ways in OpenStreetMap, and Table 2 outlines how it is determined whether an intersection is signalized or not. Traffic signals may or may not be located on the intersection's central node; if not, a proximity search within a 35 meter radius is performed, to determine whether there are nearby signals likely to be associated with the central intersection node. The number of nearby signals, in combination with OSM tag information, allows accurate determination of the signal status of an intersection in a variety of encoding cases.

Table 1: LTS classification rules for street segments based on OSM tag data.

Roadway Attributes	LTS Rank
• OSM tag “highway” is “service,” “construction,” “corridor,” “track,” “bridleway,” “road,” “proposed,” “rest_area,” or “platform,” and not designated for bicycles • Footpaths and sidewalks that don’t explicitly allow bicycles, and are not crossings • Generic paths that don’t allow bicycles	Discarded from routing
• Footpath crossings that don’t disallow bicycles • Generic paths that don’t disallow bicycles • Crossings that don’t disallow bicycles • Footpaths and sidewalks that explicitly allow bicycles • Separated cycletracks • Roadways with a bike lane, 1 lane each way, and speed limit $\leq$ 25mph • OSM tag “highway” is “residential” • OSM tag “highway” is “living_street”	LTS 1
• Restricted-access facilities with bicycle designation • Shared busways • Shared lanes with speed limit $\leq$ 25mph • Roadways with a bike lane, 1 lane each way, and speed limit $\leq$ 30mph • Roadways with a bike lane, 2 lanes each way, and speed limit $\leq$ 25mph • Roadways with $<$ 3 lanes and speed limit $\leq$ 25mph • Roadways with speed limit $\leq$ 25mph if lanes not specified • OSM tag “highway” is “unclassified,”, “tertiary,” or “tertiary_link” and has a bike lane • OSM tag “highway” is “tertiary_link” or “unclassified” and no assignment yet	LTS 2
• Shared lanes and OSM tag “highway” is not “residential” • Roadways with a bike lane, 1 lane each way, and speed limit $>$ 30mph • Roadways with a bike lane, 2 lanes each way, and speed limit $>$ 25mph • Roadways with a bike lane, $>$ 2 lanes each way, and speed limit $\leq$ 35mph • Roadways with $>$ 3 lanes and speed limit $\leq$ 25mph • OSM tag “highway” is “tertiary” and no assignment yet • Roadways with bike lanes and no assignment yet	LTS 3
• Roadways with a bike lane, $>$ 2 lanes each way, and speed limit $\geq$ 35mph • OSM tag “highway” is “primary,” “secondary,” “trunk,” “primary_link,” “secondary_link,” or “trunk_link” and no assignment yet • If none of the above rules apply	LTS 4

• OSM tag "highway" is "raceway," "motorway," or "motorway_link" and not designated for bicycles	LTS 5

Table 2: Signalization rules for intersections based on OSM tag data and signal proximity.

Intersection Attributes	**Is Signalized**
Node tag "highway" is "traffic_signals"	Yes
Node tag "highway" is "crossing" and tag "crossing" is one of ("traffic_signals," "pelican," "toucan," "pegasus," "pedestrian_signals")	Yes
Node tag "highway" is "crossing" and tag "crossing" is one of ("uncontrolled," "zebra")	No
2 or more connecting ways	
2 connecting ways with the same name (elbow in way)	No
2 or more nodes with signals within 35 meters	Yes
1 node with signals within 35 meters, and node "highway" tag is "crossing" or way "highway" tag is "cycleway"	Yes
1 node with signals within 35 meters, and not a crossing or cycleway	No
No nearby signals, or node has only 1 associated way	No

3.2 Analysis Zone Definition

This project relies on the efficient calculation of shortest paths between a very large number of origin–destination pairs given the national scope, repeated for many departure times. In order to efficiently parallelize these calculations across multiple computers, the geographical USA is divided into 4879 "analysis zones" each including no more than 5,000 Census blocks. Figure 1 shows the Census block and CBSA boundary structure for the Minneapolis–St. Paul region, and figs. 2 and 3 illustrate the process of constructing analysis zones on the national and local scales, respectively.

To simplify the calculation of local time, time zone geometries based on U.S. Census data[5] were used as parent geometries of the analysis zone areas. This way, each analysis zone is guaranteed to have a single associated time zone, whereas the use of non-time zone parent geometries would complicate local time lookup.

[5] http://efele.net/maps/tz/world/tz_world.zip

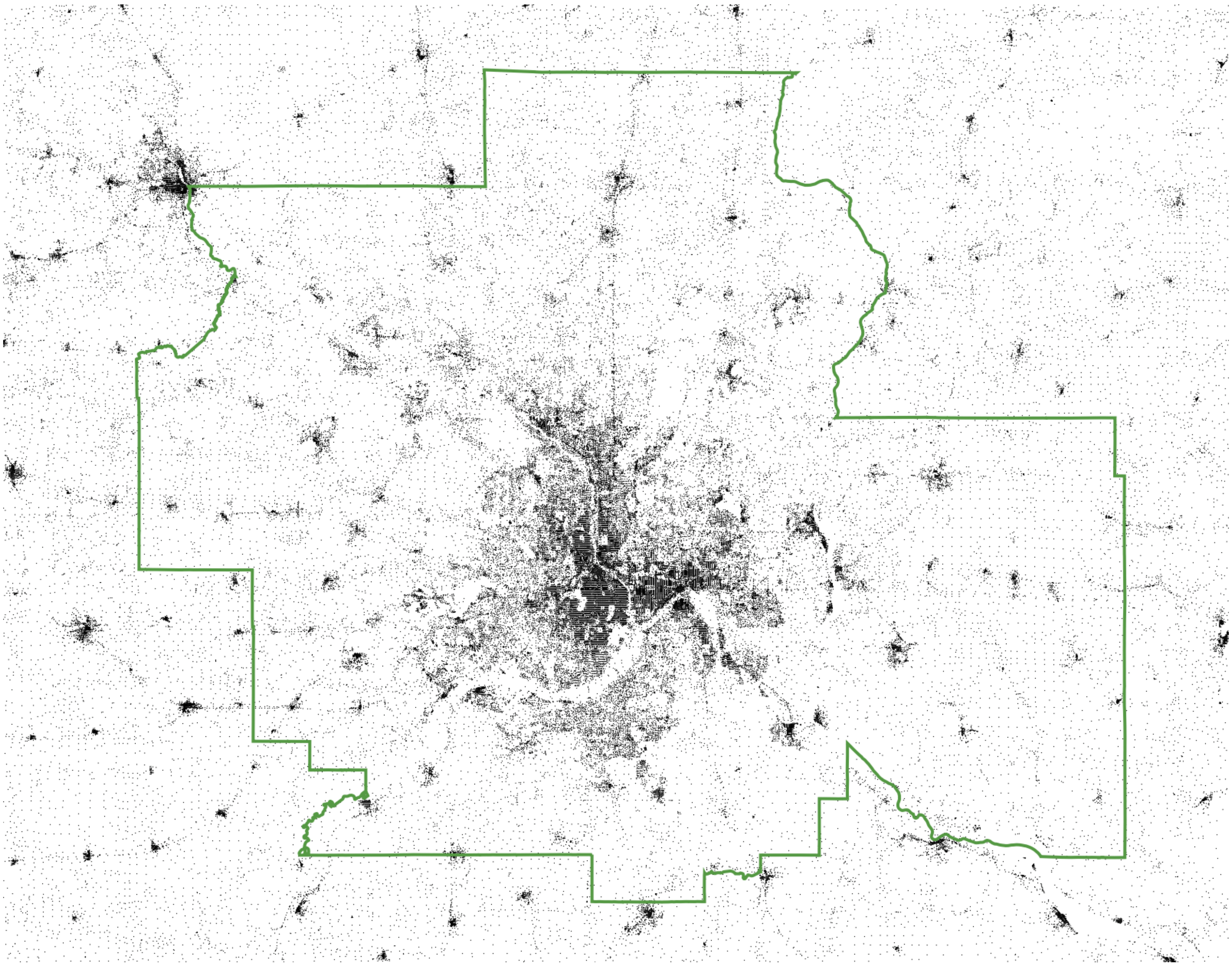

Figure 1: Boundary and Census blocks for the Minneapolis–Saint Paul, MN CBSA. Each dot represents the centroid of a single Census block.

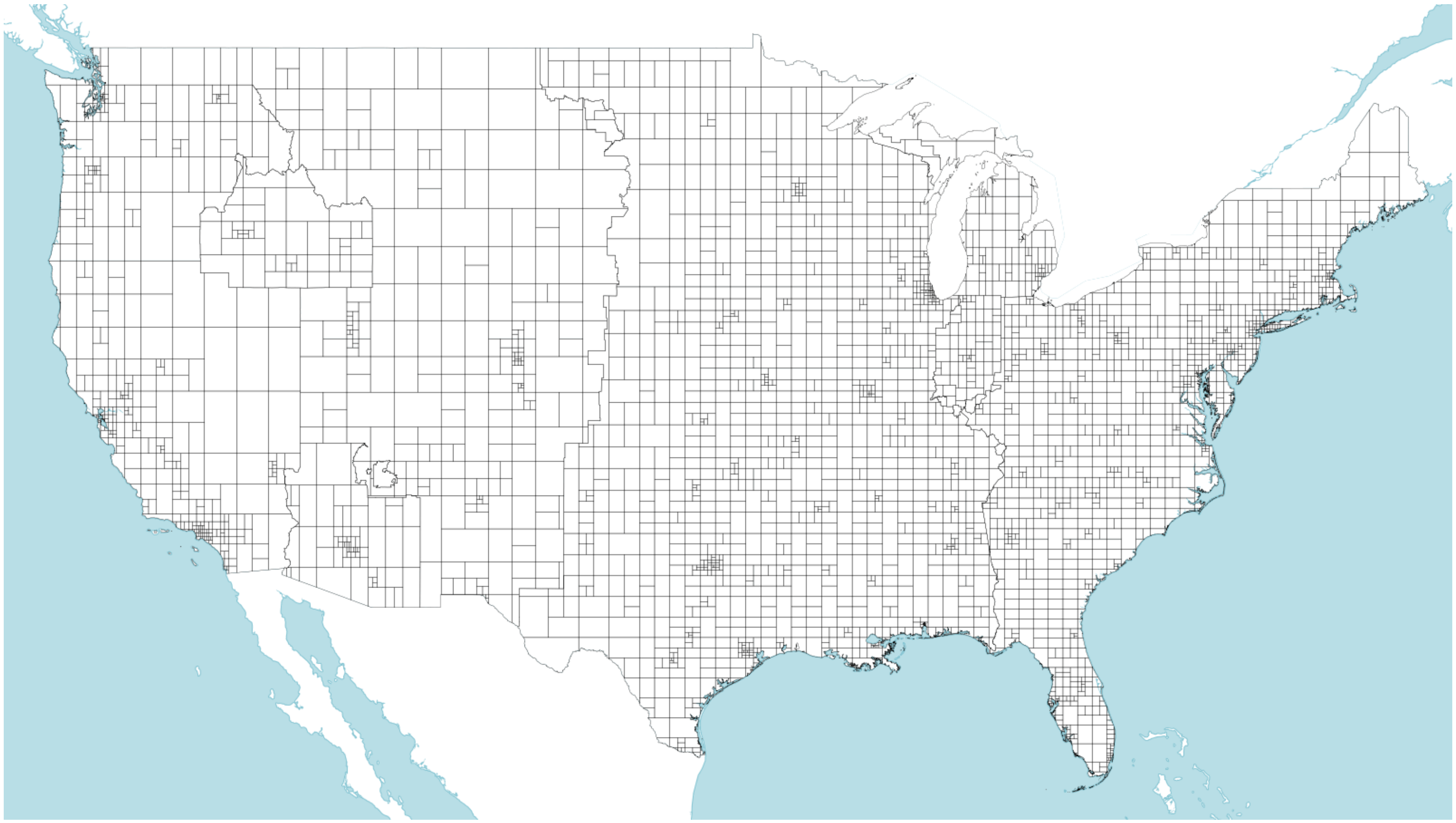

Figure 2: The United States divided into analysis zones. Each zone contains a maximum of 5,000 Census block centroids.

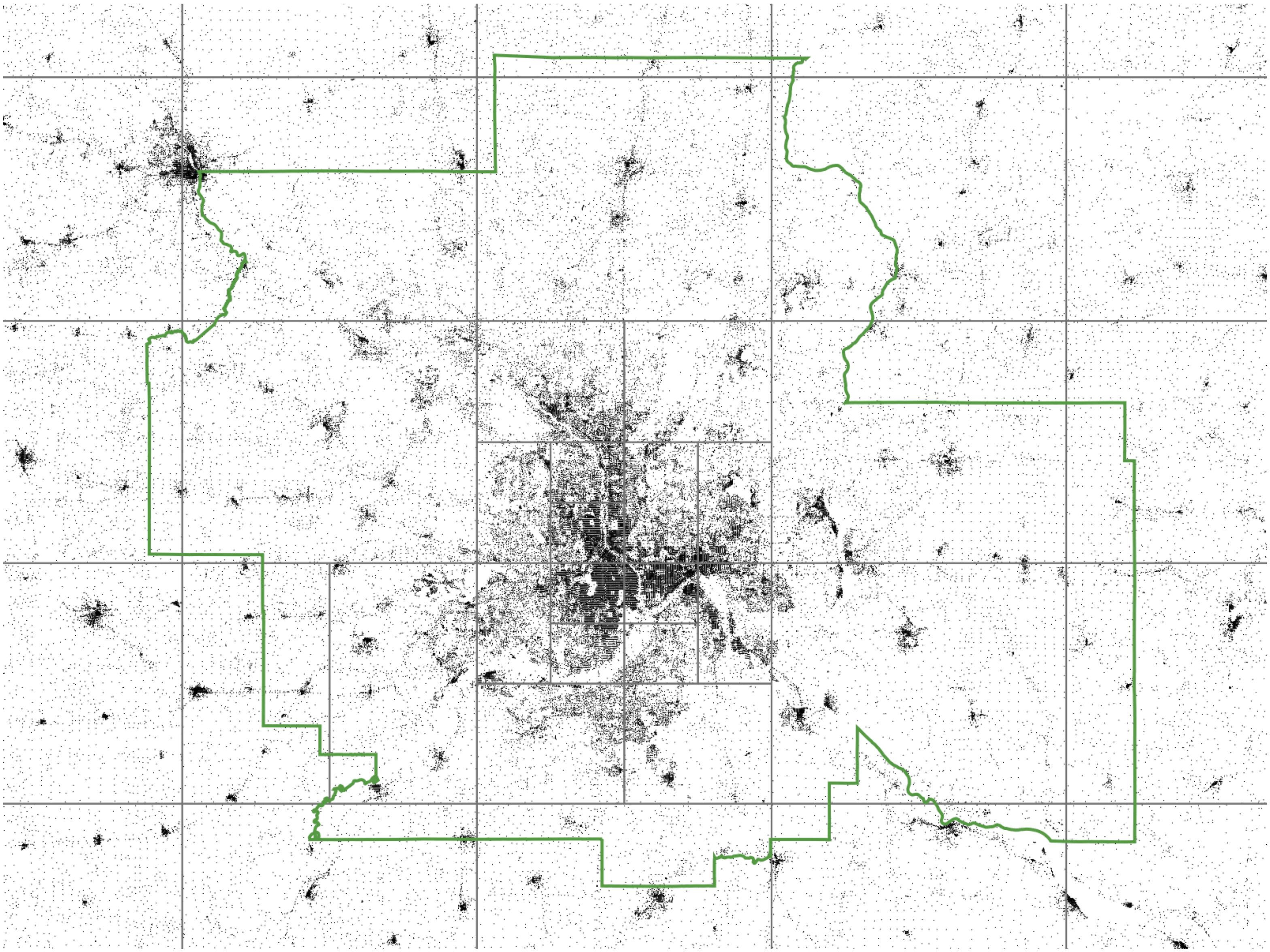

Figure 3: Example of the analysis zone structure within an urban area - Minneapolis & St. Paul, Minnesota

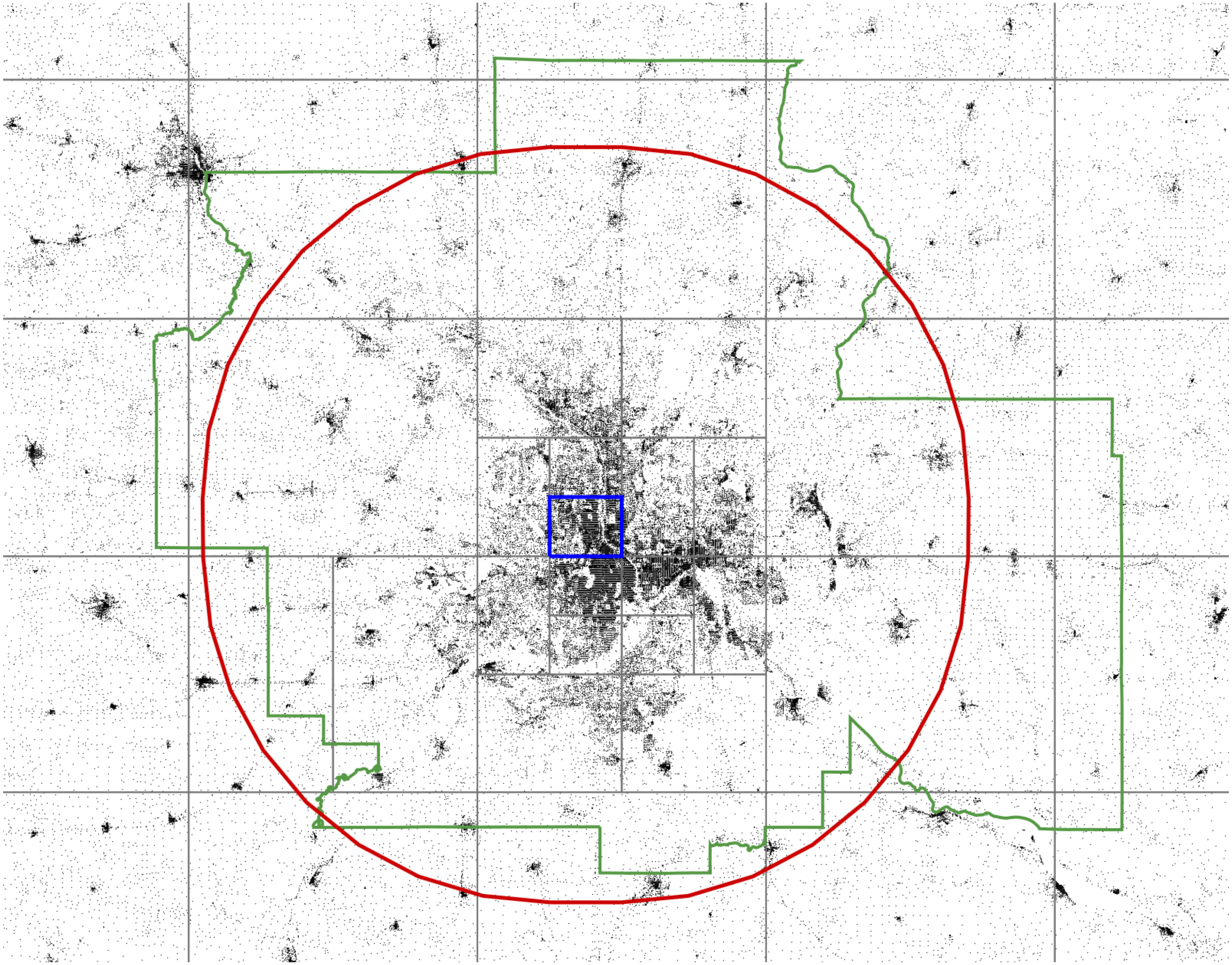

Figure 4: A single origin zone (blue) and its corresponding 60-kilometer destination zone (red). Travel times are calculated from each centroid in the origin zone to each centroid in the destination zone.

Each analysis zone defines a set of origins and a set of destinations. The origins for an analysis zone are simply those Census blocks whose centroids fall within the zone. All Census blocks whose centroids lie within 20km of the boundary of the analysis zone are included as destinations. This accounts for an average biking speed of 18 km/hour, or 5 meters per second. Figure 4 provides an example of origin and destination selection for a single analysis zone in the Minneapolis area.

3.3 Graph Building

Travel time calculations in this project are performed using the OpenTripPlanner (OTP) software, described in more detail in Section 4.2. OTP includes a graph building function that combines pedestrian and bicycle network data from OpenStreetMap into a single unified graph. A graph is built for each analysis zone. This is combined with origin and destination locations to create a single analysis bundle that contains all data necessary to calculate accessibility values for the blocks in a single analysis zone. These analysis bundles are then easily transmitted for remote computation on computer clusters.

4 Accessibility Calculation

4.1 Overview

Accessibility evaluations rely on an underlying calculation of travel times. Here, bicycle travel times are evaluated from each Census block centroid based on a detailed pedestrian and bicycle network with streets and intersections labeled with LTS scores. Travel time calculations are performed for one departure time only — noon — as bicycle trips were not modeled to be dependent on departure time. These travel times are the basis of a cumulative opportunities accessibility measure which counts the number of opportunities (in this case, jobs) reachable from each origin within 10, 20, 30, 40, 50, and 60 minutes, for a given LTS level tolerance.

This block-level dataset provides a *locational* measure of accessibility—it indicates how many jobs can be reached from different points in space. This location measure is then weighted by the number of workers residing in each Census block and averaged across the entire metro area to produce *worker-weighted* accessibility. This metric indicates the accessibility that is experienced by the average worker in the metropolitan area.

Finally, the worker-weighted average accessibility values across the 10 through 60 minute thresholds are averaged for each metropolitan area to produce a weighted accessibility ranking.

Bicycle accessibility evaluations have been performed previously on low-stress and LTS-labeled networks; Lowry et al. (2016) included a full LTS assignment procedure in Seattle within an accessibility evaluation, and Kent and Karner (2018) analyzed the accessibility to banks, supermarkets, pharmacies, and public libraries from neighborhoods in Baltimore, coupled with implementation of 106 different proposed bicycle projects. People for Bikes (2017) built a Bike Network Analysis tool to evaluate bicycle access to a variety of destination types within metropolitan areas on low-stress bicycle networks, and have performed evaluations in many cities in the United States. This present evaluation includes a few key enhancements beyond earlier and other current work: the evaluation is fully national, and includes the entire United States both within and outside of metropolitan areas, and it provides accessibility metrics for multiple travel time thresholds, rather than selecting a single threshold.

The following sections describe the specific tools, algorithms, and parameters that were used to produce the data presented in *Access Across America: Bike 2021*.

4.2 Travel Times

4.2.1 Software

Bicycle travel time calculations are performed using OpenTripPlanner (OTP), an open-source multimodal trip planning and analysis tool. OpenTripPlanner is a graph-based multimodal routing system that operates on a unified graph including links representing road, pedestrian, and transit facilities and services. OTP is available at `http://opentripplanner.org` and is described and evaluated in Hillsman and Barbeau (2011). OTP's Analyst extension provides efficient and parallelized processing of many paths from a single origin based on the construction of shortest path trees using Dijkstra's Algorithm. Additionally, locally-developed extensions to OTP allow automated batch processing of accessibility calculations for multiple departure times.

4.2.2 Bicycle Trip Parameters

When applying LTS classification to bicycle accessibility analysis, a maximal LTS tolerance is set — e.g. if a bike trip may be composed of streets and intersections of at most LTS 3, then the routing software may use only facilities classified as LTS 1, 2, or 3. The time cost of travel by bike is composed of a few different components. *Initial access time* refers to the time cost of traveling by foot from the origin to a nearby piece of the transportation network, where the traveler may begin riding a bicycle. *On-bicycle time* refers to time spent riding the bicycle on the trip. *Barrier-crossing time* refers to the time spent walking a bicycle across an intersection, or along the sidewalk of a street, of higher traffic stress than the trip's maximal LTS tolerance would allow. Finally, *destination access time* refers to time spent traveling from a nearby street link or intersection on the bicycle network to the destination. All of these components are included in the calculation of bike travel times. Bicycle travel times vary significantly depending on the maximal LTS tolerance value set, with the routes between some origin-destination pairs becoming very circuitous or impossible at lower maximal LTS values.

This analysis makes the assumption that all walking portions of the trip—initial, any barrier crossings, and destination—take place by walking at a speed of 5 km/hour along designated pedestrian facilities such as sidewalks, trails, etc. On-bicycle travel time is calculated with an assumed bicycle speed of 5 meters/second, or 19 km/h. Bicycle travel was also assumed to be insensitive to departure times and the time of day, and thus not subjected to significant congestion effects and other factors that may render bike speeds slower at certain times of day than others. On a bicycle network with significant amounts of separated infrastructure, it is reasonable to assume mixed-traffic congestion during peak periods would have a negligible effect on bicycle travel speed. Without bike infrastructure, bicycle travel times would be negatively impacted by automobile congestion, particularly where lane-splitting is illegal — however, datasets sufficiently detailed enough to model this effect are not available at a national scale. Weather and climate effects were also not accounted for, as this study constitutes a snapshot evaluation of bicycle accessibility under ideal conditions when people are most willing to bike.

4.3 Cumulative Opportunities

Many different implementations of accessibility measurement are possible. El-Geneidy and Levinson (2006) provide a practical overview of historical and contemporary approaches. Most contemporary implementations can be traced at least back to Hansen (1959), who proposes a measure where potential destinations are weighted by a gravity-based function of their access cost and then summed:

$$A_i = \sum_j O_j f\left(C_{ij}\right) \tag{1}$$

$$
\begin{aligned}
A_i &= \text{accessibility for location } i \\
O_j &= \text{number of opportunities at location } j \\
C_{ij} &= \text{time cost of travel from } i \text{ to } j \\
f\left(C_{ij}\right) &= \text{weighting function}
\end{aligned}
$$

The specific weighting function $f\left(C_{ij}\right)$ used has a tremendous impact on the resulting accessibility measurements, and the best-performing functions and parameters are generally estimated independently in each study or study area (Ingram, 1971). This makes comparisons between modes, times, and study areas challenging. Levine et al. (2012) discuss these challenges in depth during an inter-metropolitan comparison of accessibility; they find it necessary to estimate weighting parameters separately for each metropolitan area and then implement a second model to estimate a single shared parameter from the populations of each. Geurs and Van Wee (2004) also note the increased complexity introduced by the cost weighting parameter.

Perhaps the simplest approach to evaluating locational accessibility is discussed by Ingram (1971) as well as Morris et al. (1979). *Cumulative opportunity* measures of accessibility employ a binary weighting function:

$$
f\left(C_{ij}\right) = \begin{cases} 1 & \text{if } C_{ij} \leq t \\ 0 & \text{if } C_{ij} > t \end{cases} \tag{2}
$$

$$
t = \text{travel time threshold}
$$

4.4 Person-Weighted Accessibility

The accessibility calculation methods described in the sections above provide a *locational* accessibility metric—one that describes accessibility as a property of locations. The value of accessibility, however, is only realized when it is experienced by people. To reflect this fact, accessibility is averaged across all blocks in a CBSA, with each block's contribution weighted by the number of workers in that block. The result is a single metric (for each travel time threshold) that represents the accessibility value experienced by an average worker in that CBSA.

4.5 Weighted Accessibility Ranking

Metropolitan area rankings are based on an average of person-weighted job accessibility for each metropolitan area over the twelve travel time thresholds. In the weighted average of accessibility, destinations reachable in shorter travel times are given more weight, as they constitute more attractive destinations. A negative exponential weighting factor is used, following Levinson and Kumar (1994). Here time is differenced by thresholds to get a series of "donuts" (e.g. jobs reachable from 0 to 10 minutes, from 10 to 20 minutes, etc.).

$$a_w = \sum_t (a_t - a_{t-10}) \times e^{\beta t}$$

a_w = Weighted accessibility ranking metric for a single metropolitan area
a_t = Worker-weighted accessibility for threshold t
$\beta = -0.08$

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