TECHNICAL PAPER

CUBE Access: Methodology and Application

Bentley
Advancing Infrastructure

HOW CAN WE MEASURE TRANSPORTATION ACCESSIBILITY?

Transportation accessibility has become a popular topic in city planning. A city's accessibility determines whether you need a car to run errands or get to work. Subsequently, accessibility determines how active our community can be. For example, can city residents walk or bike to parks and other attractions, or must they drive?

But how can we measure accessibility correctly? In this paper, a methodology for measuring accessibility within the CUBE Access software will be defined. The paper will also explore different analysis practices that might be implemented for planning.

ACCESSIBILITY ANALYSIS USING ZONAL SYSTEMS

There are two main components of accessibility – the origin and the destination of a person's trip. This could include their home, their place of work, or their favorite grocery store. For efficiency purposes, zones are used to summarize singular destination points. Therefore, origin and destination point data, such as stores and office buildings, must be summarized within zones to analyze their accessibility.

The value of the specific destination or point of interest within the zone can be summarized within S_{jk}, where S_{jk} represents the sum of destinations type *k* in zone *j*. This could represent the counting of singular destination points such as stores, or the summing of more representative destination metrics such as the amount of retail floor space. By summarizing these values within the zones, access to these zones can be seamlessly represented by also having access to those stores or the amount of retail floor space within the zone.

This is shown in Figure 1 and Figure 2 below:

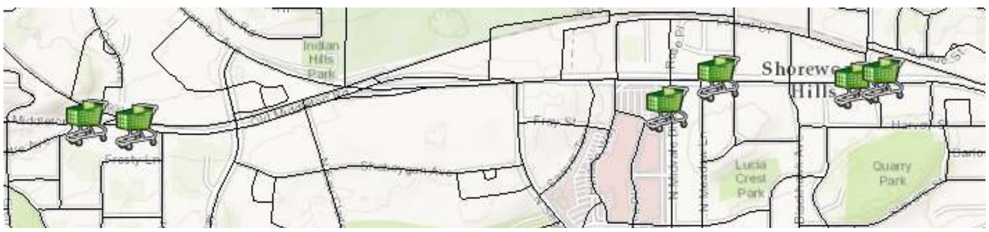

Figure 1: Grocery stores represented by points of interest within CUBE Access Database.

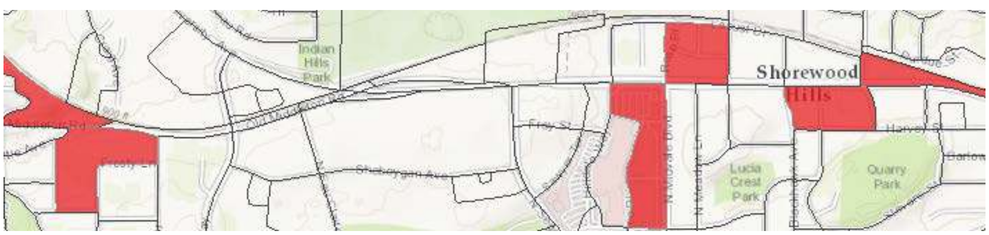

Figure 2: Points of interest summarized within a zonal system.

As a default within CUBE Access, census blocks are used as a zonal system in the United States. Demographic information, such as population and employment figures, are already calculated for this zonal level by the U.S. Census and are included in the CUBE Access data package. Depending on the type of accessibility analysis that is trying to be accomplished, such as local walking accessibility, differently sized zonal systems can be used. For instance, a parcel-based zonal system can serve as a replacement for analyzing point-to-point accessibility, as seen in Figure 3. However, when attempting to analyze regional accessibility across a metropolitan region, consider using aggregated Census zones such as block groups. Outside of the United States, local zonal systems may also be used for accessibility analysis. In addition, there are several geoprocessing applications that can automatically generate local zoning systems if they are not readily available.

ACCESSING THE ORIGIN AND DESTINATION ZONES FROM THE LOCAL NETWORK

Measuring transportation accessibility requires origins and destinations to be connected within the accessibility model via the transportation network, which would mean creating additional links.

To connect the zones, a centroid is defined for every zone and placed at the geometric center of each zone through an automatic geoprocessing process. From the zone centroids, links are then created to every adjacent roadway link to the zone. Based on the mode of travel being assessed, only roadway links with the same mode allowance will be connected to the zone.

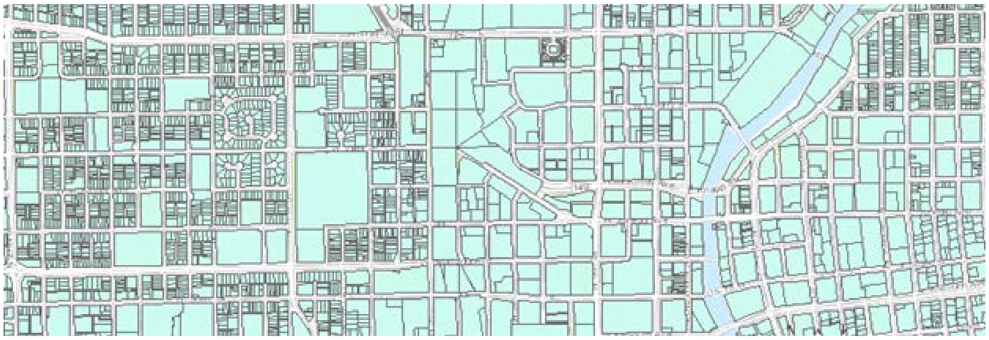

Figure 3: Parcel level zonal system within CUBE Access.

CALCULATING TRAVEL TIMES BETWEEN ALL ZONES

Accessibility analysis consists of thousands of individual travel time isochrones across every individual origin zone. These isochrones provide the capability to understand and analyze every potential trip an individual could make. To develop these isochrones, the travel times between every individual zone pair in the analysis area must be computed on an individual modal level, such that the travel time matrices between zones, for example travel time skims, are produced for each mode of travel.

Travel times can be calculated accurately for each individual mode because of the detailed underlying transportation networks. Each roadway link consists of several modal attributes describing the modes of travel allowed on that link.

Total travel times between origin and destination zones comprise of three different travel times:

- *Network Egress Travel Time* – The time it takes to traverse the origin zonal connectors and reach the roadway network.
- *Network Travel Time* – The time it takes to traverse the roadway network between an origin zone connector and a destination zone connector using only mode-specified roadway links.
- *Network Ingress Travel Time* – The time it takes to traverse the destination zonal connector and reach the destination's centroid.

Travel times are calculated to the centroid of each zone so that there is no travel time bias based on the size of the origin or destination zones. Pedestrian and bicycle network travel times are calculated in a straightforward fashion using user-specified speeds for each individual mode. Automobile network travel times, for example, use realistic roadway link drive times that are specified by time of day to appropriately replicate the effects of congestion on the roadway network throughout the day.

Multimodal network travel times comprise both pedestrian and transit network travel times. Transit network travel times are based on general transit feed specification (GTFS) data that is summarized into sets of transit lines with specified headways and run times. The entire multimodal network travel times comprise the following steps and can be visualized in Figure 4:

- *Walk to Transit Travel Time (A)* – The time it takes to walk from the origin zone centroid to the transit stop of the best route as defined in the route enumeration process.
- *Transit Wait Time (B)* – Calculated relative to the transit line's headway with a specified maximum wait time.
- *Transit Run Time (C)* – The run time as defined by the transit line's attribute between a boarding transit stop and an alighting transit stop.
- *Transfer Wait Time (D)* – Calculated relative to the transit line's headway with a specified maximum transfer time.
- *Walk to Destination Travel Time (E)* – The time it takes to walk from an alighting transit stop to the destination zone centroid.

Figure 4: (A) (B) (C/D) (E)

CHOOSING THE BEST TRANSIT ROUTE

People tend to travel in a fashion that utilizes the shortest path from their origin to their destination. This is the methodology implemented for routing pedestrian, bicycle, and driving modes when computing travel time accessibility metrics. Transit routing can be a bit more complex, as riders tend to choose from a larger set of potential routes that will get them from their origin to their destination. To accurately reflect the potential routes, a route enumeration and evaluation methodology is implemented in which the cost is calculated for each potential route set between every stop node, together with the probability of choosing the different routes. The probability that each of these routes are taken is frequency based and shown below:

The resulting multirouting cost is averaged to form a composite stop-to-stop cost. The actual routing between origins and destinations is then achieved in a second step, where routes are broken down by both the amount of in-vehicle and out-of-vehicle travel times, as well as the amount of transfers, with each adding a different cost for the entire route.

$$P_{(uselineI)} = \frac{Frequency_{(lineI)}}{\sum_{k} Frequency_{(lineK)}}$$

CALCULATING ACCESSIBILITY METRICS

Accessibility can be measured and calculated in different manners. Simple accessibility metrics consist of analyzing the travel times to specific destinations, while other metrics can measure access to a multitude of destination types. These destinations refer to types of points of interest (POIs) or land uses, rather than specifying a destination zone. All of these metrics are still considered accessibility metrics, meaning they analyze the travel times between different types of land use, however, they may be defined differently.

Accessibility metrics may not only be defined differently in how they are calculated but also in how they are applied. Transportation accessibility has both modal and temporal aspects that also need to be considered. CUBE Access implements several common accessibility metrics that are used and applied in different manners. These metrics can analyze accessibility to different types of destinations for different transportation modes and at different times of day. The three types of accessibility analysis used within CUBE Access are explained in the following paragraphs.

TRAVEL TIME ANALYSIS

The travel time accessibility metric analyzes the minimum travel time to a particular type of destination or point of interest. All accessibility metrics are therefore calculated for every zone in the analysis area. In many cases, there may be multiple destinations (POIs) that are being analyzed, such as grocery stores throughout a city. In this case, the analysis will demonstrate the minimum travel time to reach a grocery store for the entire population. The Travel Time accessibility metric is defined in the equation below:

$$T_{ik} = \min(t_{ij}) \textit{ for } S_j > 0$$

T_{ik} = *Travel Time Accessibility for zone i to destination k*
S_{jk} = *Sum of destination (POIs)k within zone j*
t_{ij} = *Travel time between zone i and j*

DESTINATION SUMMATION

The destination summation accessibility metric analyzes the cumulative access to a destination of a particular type. Therefore, for every zone in the analysis area, the metric will determine the number of destinations (POIs) that are accessible within a certain travel time threshold. For instance, in measuring the accessibility to job opportunities, the analysis will demonstrate the number of job opportunities that are accessible within the specified travel time threshold. The destination summation accessibility metric is defined in the equation below:

$$D_{ik} = \sum_j S_j \, f(t_{ij}) \text{ where } f(t_{ij}) = \begin{Bmatrix} 1 \text{ if } t_{ij} \leq T \\ 0 \text{ if } t_{ij} > T \end{Bmatrix}$$

D_{ik}=Destination Summation Accessibility to destination k for zone i
T=Travel time threshold

ACCESS SCORE

The access score accessibility metric also analyzes the cumulative access to destinations. However, it implements a decay cost function in addition to allowing analysis to multiple destination types in one metric. The formula sets a user-defined target number of POIs for each category, such that the target defines the number of POIs desired to consider an origin sufficiently accessible to that particular destination type. The metric then assigns a portion of the total score, typically out of 100, to be awarded for the category if this target is met. This open methodology also utilizes individual POI weight factors to customize an Access Score to depict different trip types. These two factors are organized in a user-defined table such that the factors can be chosen for each specific POI category as the user sees fit. The outline of the access score lookup table can be seen below:

POI Category	POI Target	POI Category Weight
1	P_1	W_1
2	P_2	W_2
...	...	...
n	P_n	W_n

The addition of a decay cost function allows each destination to be weighted differently based on a person's willingness to travel. The cost function implemented for walking trips is based upon U.S. National Household Travel Survey data. The function adjusts the relative value of destinations based upon their proximity to the origin. A gravity-based function is implemented such that it accurately reflects a person's willingness to travel as they travel farther and farther away from their origin. The cost function is graphed in Figure 5 below:

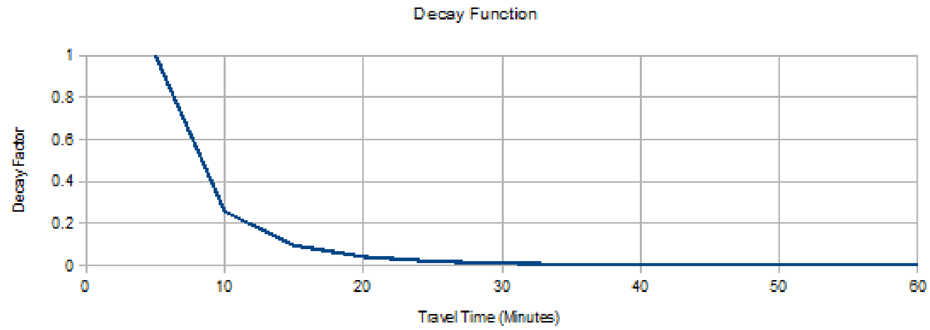

Figure 5: A walk travel time decay cost function.

These factors and cost functions come together to define the access score metric; the equation is outlined below:

$$AS_{ik} = \min\left(\sum_j (S_{jk}\, f(t_{ij})), P_k\right)$$

$$AS_i = \min\left(\sum_k \frac{AS_{ik}}{P_k} W_k, 100\right)$$

AS_i = Access Score Accessibility for zone i
k = Destination (POI) type indicator
S_{jk} = Sum of destinations (POIs) within zone j for destination (POI) type k
$f(t_{ij})$ = decay cost function
P_k = Points of interest target for POI type k
W_k = Points of interest weight for POI type k

CITYWIDE ACCESSIBILITY METRICS

The citywide accessibility metric allows for individual zonal accessibility metrics to be averaged across entire cities and regions. These average accessibility metrics can be one of any of the three defined metrics above and be weighted by any type of population group as defined below:

$$A_N = \frac{\sum_i A_i N_i}{\sum_i N_i}$$

A_N=Weighted accessibility metric for population group N
N_i=Number of population group in zone i

ANALYZING ACCESSIBILITY WITH CUBE ACCESS

This section explores how to apply CUBE Access to analyze accessibility in their local area. Accessibility analysis is a scalable and transferable concept. Although this section focuses on data from the United States, the same workflow for analyzing accessibility shown throughout this section can be used around the world. This transferability is due to how data sources, such as the HERE roadway network and POI database, as well as GTFS data, are globally available and present a uniform model structure.

EXPLORING THE DATA WITHIN CUBE ACCESS

CUBE Access is a ready-to-use software package for accessibility analysis. All data necessary for accessibility analysis purposes is stored within an Esri formatted personal database. There are four major components for running accessibility analysis, including:

- Zonal Data – ArcGIS polygon feature class representing the local zonal system.
- Roadway and Pedestrian Network – Developed by the navigation company, HERE, and converted for analyzing accessibility within CUBE Access.
- Transit Network – Converted from local GTFS files and summarized into specific transit lines with headways and run times.
- POI Dataset – A local points of interest database used by HERE.

More information about the data, specifically within the CUBE Access data package, can be found in the CUBE Access metadata sheets.

LAUNCH PAD WORKFLOW

CUBE Access utilizes a scenario-based workflow for exploring different accessibility analyses through the Launch Pad in the ArcGIS desktop. Users may set up base scenarios pertaining to a particular transportation network and demographic data. Within that base scenario, users can explore different accessibility analyses, including different destination types and transportation modes, as seen to the right in figure 6.

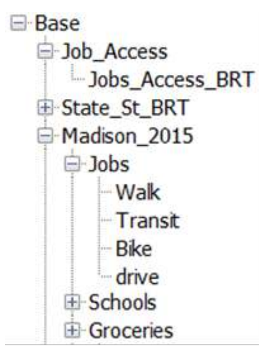

Figure 6: Launch Pad Scenarios

Under the 'Base' scenario in launch pad, we have created a Madison_2015 scenario pertaining directly to the transportation and land use data that is contained within the provided geodatabase. Three additional scenarios within Madison_2015 have been created to analyze accessibility to three separate types of destinations – jobs, schools, and grocery stores. Within each of those destination scenarios, we created more scenarios to analyze accessibility across different transportation modes.

Analysis scenarios are set up by choosing the analysis parameters as well as the specific reference files. This is done on an individual basis within each of the four CUBE Access applications:

- Accessibility Calculator – Produces the accessibility metrics for the travel time analysis and destination analyses.
- Access Score – Produces the accessibility metrics for the Access Score analysis.
- Map Mixer – Compares two accessibility analyses.
- POI Summary – Summarizes individual point destinations into analysis zones.

Once users have prepared accessibility analysis scenarios within one of the applications, they may run the scenario. Scenario runs are all completed in the cloud and made available to the user once they are completed. Users may download their analysis results directly to their desktop or view them in ArcGIS Online.

DEMONSTRATION SCENARIO 1: ANALYZING CURRENT ACCESSIBILITY

CUBE Access comes with a complete accessibility data package allowing users to run accessibility scenarios once they receive their CUBE Access subscription. Suppose a user wants to understand the level of accessibility to current employment opportunities in the region and how they might differ from driving and using public transportation. The following process outlines how the proposed scenario can be set up within the launch pad.

INTRODUCTION

The data included in the CUBE Access demo includes real land use and transportation data from the city of Madison, Wisconsin in the United States. The population within the dataset is summarized into U.S. census blocks, which are the lowest level of disaggregated population data used in the U.S. The population of the study area is just above 200,000 people, summarized within 4,000 census blocks or zones. The local HERE roadway network is used for the area along with local points of interest. The local GTFS feed was also used to obtain the transit network, with some lines removed for simplicity's sake.

SET UP A BASE ANALYSIS WITH THE CURRENT TRANSPORTATION NETWORK AND DEMOGRAPHIC DATA

The CUBE Launch Pad functions as an accessibility scenario manager, such that all sub-scenarios, also known as child scenarios, inherit the analysis parameters and file references of the base scenario, or the parent scenario. Thus, it is important to first define those analysis parameters and file references in the base scenario before other scenarios are created. This is done under the base scenario Madison_2015 within the accessibility calculator application as seen previously in figure 6.

Within the base scenario, the user will define all of the attributes that will be common for all current accessibility analysis, e.g., file references that refer to the network and land use data from the provided geodatabase. Therefore, the user may provide the following inputs for the required file references:

- Analysis Polygons – (CUBEAccess.mdb\Census_Blocks)
- Roadway Network – (CUBEAccess.mdb\HWNetwork)
- Turn Prohibitions and Penalties – (TurnProhibitors.pen)
- Public Transit Lines – (CUBEAccess.mdb\ptlines)

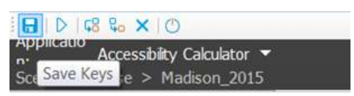

Figure 7: CUBE Access drop-down options

Other inputs may be set either as blank or as their default values. The user should save the Madison_2015 scenario once these files have been appropriately referenced.

SET UP AN ANALYSIS TYPE WITH A SPECIFIC DESTINATION

To set up a sub-scenario of employment accessibility within the base scenario, Madison_2015, the user shall right click on the scenario to add the Jobs child scenario, as seen on the right. Within that scenario the files that were referenced in the base scenario should still be referenced in the jobs sub-scenario.

Within the jobs scenario, the user will define all the attributes that are common for all the employment accessibility analysis. These inputs should be consistent with the type of analysis and should include:

- Type of Analysis – (Dest_Summation)
- Destination Type – (Jobs)
- Travel time cutoff (20)
- Time Period (1)
- Map Population Field (Population)
- Upload to AGOL ("check")
- Average Walking Speed (3.5)
- Average Cycling Speed (9.1)

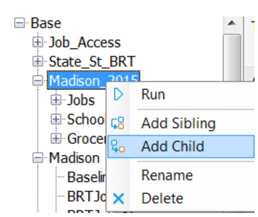

Figure 8: CUBE Access scenario management interface

The main input for the analysis scenario level is the type of analysis. In this case, the user should select Dest_Summation. With this analysis, the total number of the particular destinations in the Jobs sub-scenario accessible within the travel time cutoff will be summed for each origin. Notice that the destination type dropdown field is populated with the land use data that is summarized within the analysis zone. The next step is to save the jobs sub-scenario once the appropriate types of the analysis parameters have been referenced.

SET UP INDIVIDUAL ACCESSIBILITY ANALYSES

To set up the accessibility analysis scenarios within the jobs analysis type scenario, the user can right click on the scenario to create children scenarios. These two scenarios will be for the transit and driving accessibility analysis scenarios as seen on the right. Again, these sub-scenarios should inherit the parameters of the parent scenario.

- Mode of Travel – ('Transit' for public transport, 'Auto' for driving)
- Is driving an option – (check to allow driving)
- Use public transit lines – (check to allow public transport)

At this point, both accessibility scenarios have been fully defined and are ready to run. Once each scenario has been saved individually, the user may run the scenarios.

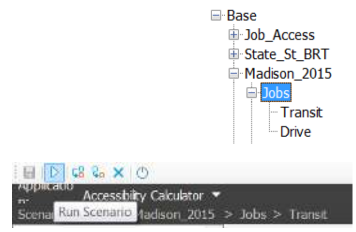

Figure 9: CUBE Access scenario interface

VIEW AND ANALYZE ACCESSIBILITY RESULTS

Once the analysis, which may take 30 minutes to 40 minutes, has been completed, the results will be available for download or upload to ArcGIS Online. The user can open up both of the analysis results in ArcGIS Online through their My Content page as seen in Figure 10 below:

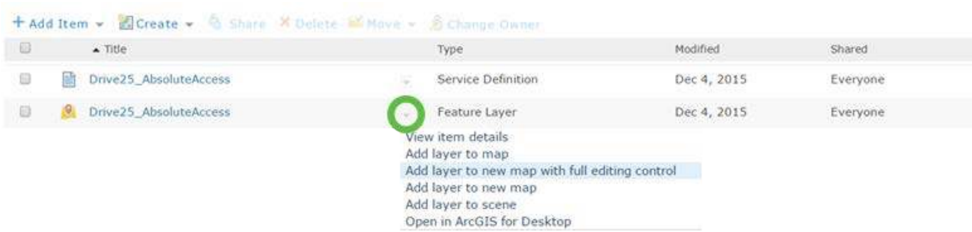

Figure 10: The ArcGIS Online My Content interface.

Within ArcGIS Online, users have the option to customize their map through the Change Style option.

Note that the application is mapping the Sumdests column, which equates to the accessibility metric that is calculated for each zone, which is the number of employment opportunities accessible within 25 minutes via public transportation.

For comparison sake, it is important to specify the class intervals for the driving analysis first. That will make enough room on the scale for analyzing both driving and transit accessibility. A user may choose the same intervals as on the left or choose their own. However, the intervals should be the same for both the Transit and Driving accessibility maps. The option is available to round classes for clarity. Once specified to the liking of the user, the two accessibility maps should be saved with the following names – Transit Job Access and Drive Job Access. The Tags and Summary fields may be completed to the liking of the user.

The user can then explore different options to view and compare different accessibility analyses. ArcGIS Online offers web applications including the Map Series Builder, which can be a great tool to compare two maps. Through the Map Series Builder, the user may reference both recently created accessibility maps in this scenario, Transit Job Access and Drive Job Access, and create their own shareable web application illustrated below. For more information about building these and other web applications in ArcGIS Online, please visit ArcGIS Online web applications.

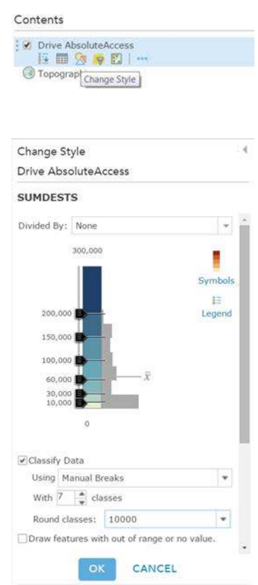

Figure 11: Charting representation of driving access

DRAWING CONCLUSIONS

Accessibility metrics are quantifiable and enable us to directly compare one with the other. Transportation accessibility metrics may be compared across different modes and at different times of the day. In this analysis, there is a large discrepancy between job accessibility when driving and when taking public transportation. That discrepancy is minimized in the central locations within the city where there is a higher connectivity to the transit system. These initial comparative analyses should give way to further investigations including other scenarios, such as analyzing changes to transit systems to increase access to jobs around the city.

If you have any questions, please contact us.

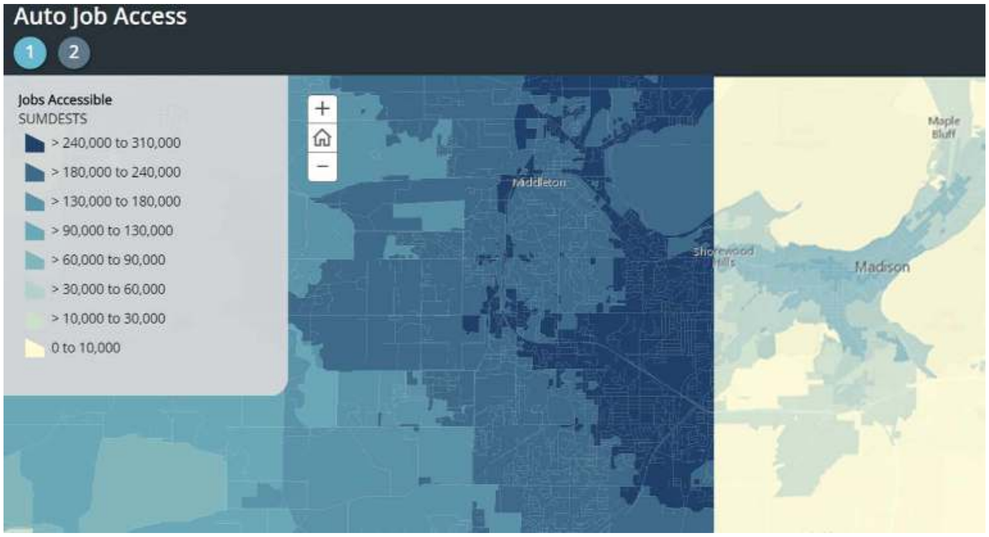

Figure 12: CUBE Access results via geographic information system (GIS) mapping