OZARKS TRANSPORTATION ORGANIZATION

A METROPOLITAN PLANNING ORGANIZATION

Final REPORT

CITY UTILITIES OF SPRINGFIELD TRANSIT SERVICES ORIGIN/DESTINATION ACCESSIBILITY ANALYSIS

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EXECUTIVE SUMMARY

City Utilities of Springfield (CU) Transit Services provides fixed route bus service in Springfield, Missouri. Bus service operates 365 days a year. There are 12 weekday daytime routes, seven Saturday and evening routes, and four Sunday and holiday routes. The CU Transit Services service area encompasses 95 square miles and includes the city limits of Springfield and outlying areas within three quarters of a mile from existing routes.

The Ozarks Transportation Organization (OTO) serves as the Metropolitan Planning Organization (MPO) for the Springfield, Missouri metro area. As the area MPO, the OTO supports CU Transit Services planning to develop route and schedule alternatives to make services more efficient and cost effective.

The CU Transit Origin/Destination (OD) Accessibility Analysis was prepared to support bus route service planning. This analysis incorporates tools developed by Esri, the makers of ArcGIS software, GTFS data to create a multimodal network dataset for route solving in the Network Analyst extension of ArcGIS. The GTFS tables enable the calculation of travel time along a transportation network based on walking speed and time-aware bus routes and schedules.

The GTFS data format was created by Google and the Portland, Oregon TriMet transit agency to share routes and schedules in web-based customer-facing trip planners [1]. In addition, GTFS data are used in Google Maps for the option to get directions using transit services.

A grid of hexagons was enriched with authoritative content from Esri demographics for 2018 population estimates and 2018 daytime population estimates. Hexagons with a positive difference in 2018 resident population and 2018 daytime population were used to represented where people were going in the CU Transit Services area. The total daytime population change was used as a weighted value representing its attractiveness.

Esri 2018 population estimates were used as a baseline to estimate demographics for census blocks in conjunction with OTO housing unit data and 2012 – 2016 ACS Five-Year Estimates. Populated census block point features were used origin locations from which individuals would travel to destinations using the network dataset created using CU Transit Services GTFS data.

An OD cost matrix was solved at one-minute intervals during a one-hour time window for current daytime routes and schedules in Network Analyst using Esri developed transit analysis tools. This process was repeated in an evaluation of night routes scheduled with 15-minute and 20-minute headways at stops to compare the change in accessibility to activity centers current daytime routes to night routes with increased frequency.

The census block population estimates are used as a metric to describe the impact of changes to routes and schedules on the resident population in terms of access to activities.

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INTRODUCTION

Accessibility is defined as the ease of getting from one place to another. It can be measured in distance or time and is used to analyze the efficiency of connecting people and places on a transportation network [2]. Transit accessibility measures have two core elements, an activity element and a transportation element. The activity element includes opportunities, jobs, or services at a destination. The transportation element reflects the cost of travel in time or distance [1]. The workflow for this project follows a five-step GIS analysis process:

1. Frame the question
2. Explore and prepare data
3. Choose analysis methods and tools
4. Perform the analysis
5. Examine and refine results

The questions framed by this analysis include:

- How well are transit services connected to major daytime activity centers in the CU Transit Service area?
- What is the demographic composition of people in locations that have the greatest and least transit access to activity centers?
- Are there more efficient route and schedule alternatives to connect people to activities via transit in the service area?

Much of the data needed to analyze transit accessibility on a multi-modal network is maintained by the OTO or partner organizations. A network dataset of Christian and Greene Counties was provided by the City of Springfield GIS Department. Greenway Trails, sidewalks, and census data are maintained by the OTO. Bus routes and schedules in GTFS format were provided by CU Transit Services.

The use of GTFS data to conduct evaluation of bus routes and schedules has increased due to the ability to add GTFS data to network datasets in GIS software and to conduct time-aware analysis of trips using the transit system. Calculating travel times using transit have been difficult to incorporate into GIS due to the varying frequencies and times buses arrive at different stops [3]. As recently as 2015, ArcGIS software did not have the capabilities to integrate transit schedules into multi-modal networks to measure time-based accessibility in Network Analyst [4].

In 2016, Melinda Morang at Esri created tools for adding Google Transit Feed Specification (GTFS) data to ArcGIS and transit analysis tools that use time-aware network datasets [5]. These tools are available for download at http://esri.github.io/public-transit-tools/ [6] Using these tools, given a set of origin and destination points, the number of reachable destinations by walking and transit within a time limit can be determined [7]. Thusly, the transportation element of the accessibility measure can be calculated.

To complete this study with current information, a method for updating population data at the census block level was used for determining 2018 population attributes for census blocks.

Enriched hexagons with 2018 Esri population estimates were used as a baseline to estimate 2018 census block population and socio-economic characteristics based on OTO area housing unit construction and demolition permits from 2010 – 2017. The 2010 – 2017 permit data were added to the 2010 decennial census number of housing units to estimate 2018 population. Estimates of socio-economic variables for census block groups from the 2012 – 2016 Five-Year American Community Survey were used to estimate the variables at the census block level. The updated 2018 census block demographics were then used to describe attributes of the population within a travel time threshold for a combination of walking and transit time along the streets and bus routes. The census block centroids with a population greater than zero were used as the set origin points.

ArcGIS Online Living Atlas includes a map layer with attributes for 2018 daytime population estimates. The daytime population was subtracted from the total resident population of an area to represent the attractiveness of destinations people travel to for work or other activities. A grid of hexagons was enriched with the daytime population change to use as the activity element of the transit accessibility analysis for the CU Transit Service area. Figure 1 on page 3 is a map depicting the daytime population change values for the enriched hexagons. Hexagons with a net positive change in daytime population were used as weighted destinations from census block origins in an origin/destination (OD) cost matrix created in Network Analyst.

The census block origins and enriched hexagon destinations were used as inputs to solve an OD cost matrix using the Network Analyst extension in ArcMap. Three multimodal network datasets were used to develop an accessibility measure for CU Transit Services current weekday day bus routes, weekday night routes with 20-minute headway for stops, and weekday night routes with 15-minute headways for stops. The headway times equate to running 3 and 4 busses on night routes every hour. Currently busses run on night routes with 60-minute headways or once per hour.

The GTFS files were modified to increase the number of trips on night routes to test the efficiency of running fewer routes at greater frequency and investigate the change in accessibility to activity centers. The estimates for socio-economic population characteristics at the census block level were summarized by hexagons to describe populations with the greatest increase in accessibility and those with the greatest decrease.

Figure 2 on page 4 is a map of weekday daytime bus routes in the CU Transit Services area. Figure 3 on page 5 is a map of weekday night routes. Background information on data preparation and analysis tools are detailed in subsequent sections of this report. The output and results of the analysis are presented in maps and tables in the final section followed by a summary of conclusions.

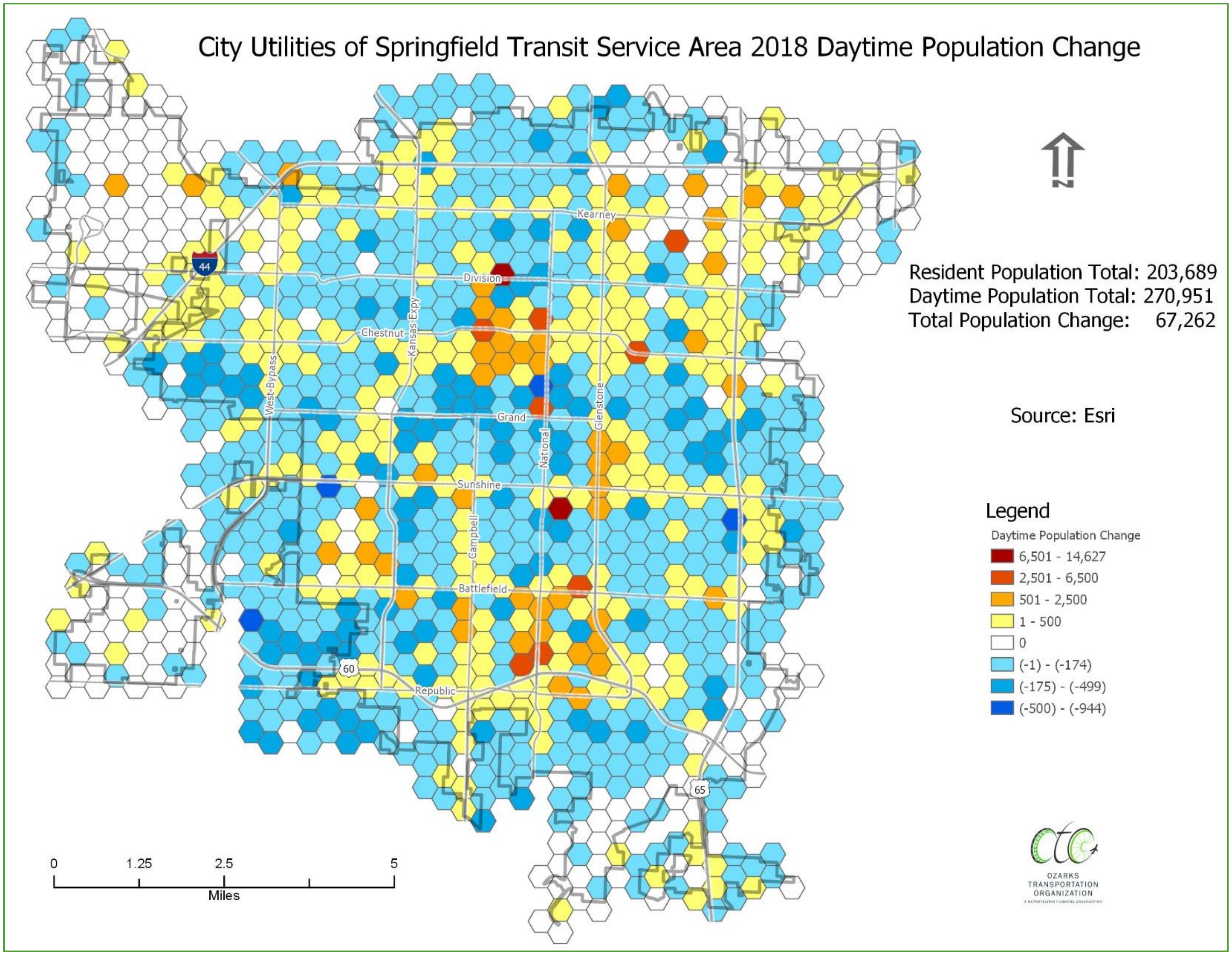

Figure 1: CU Transit Services Area Daytime Population Change

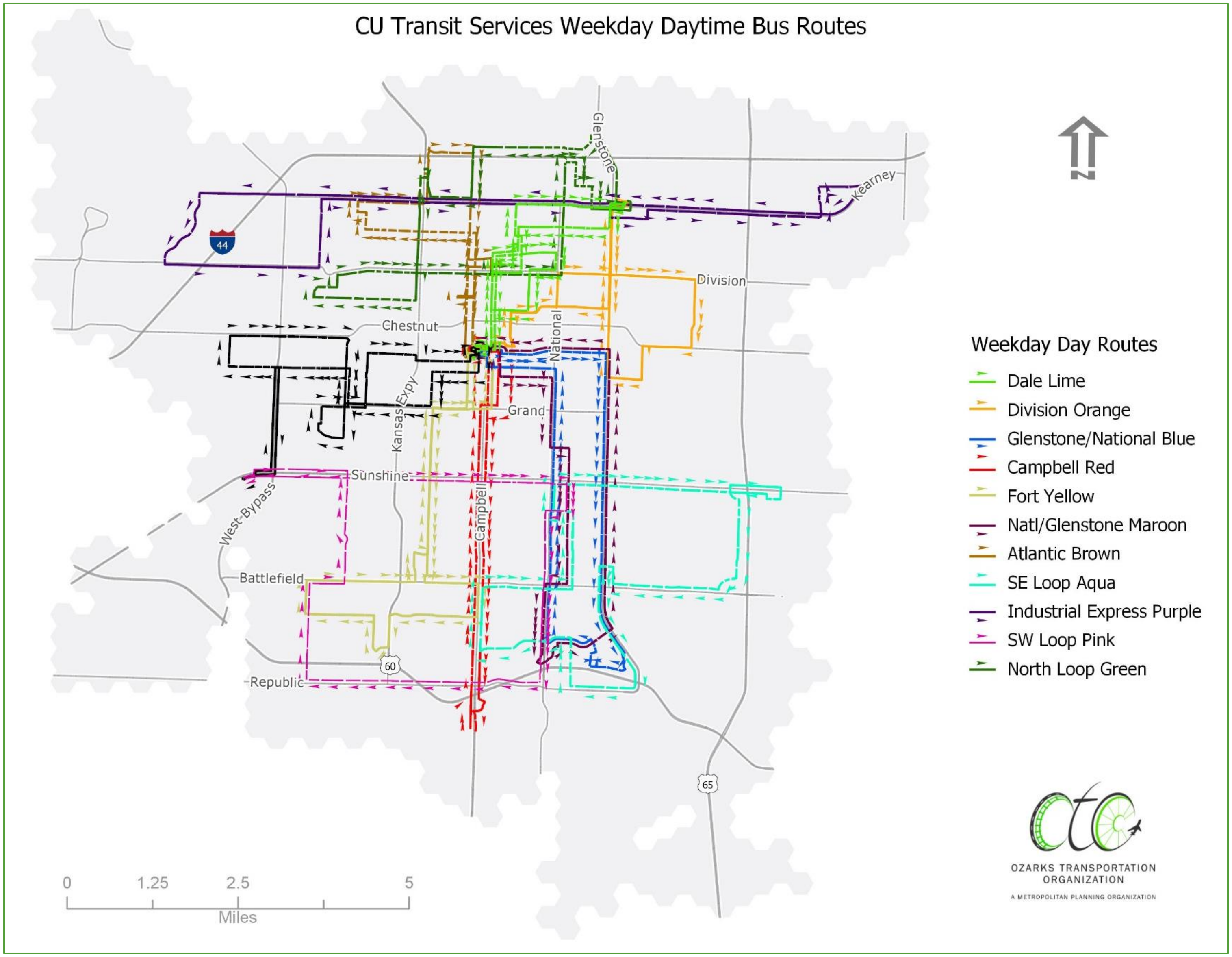

Figure 2: Map of CU Transit Services Weekday Daytime Bus Routes

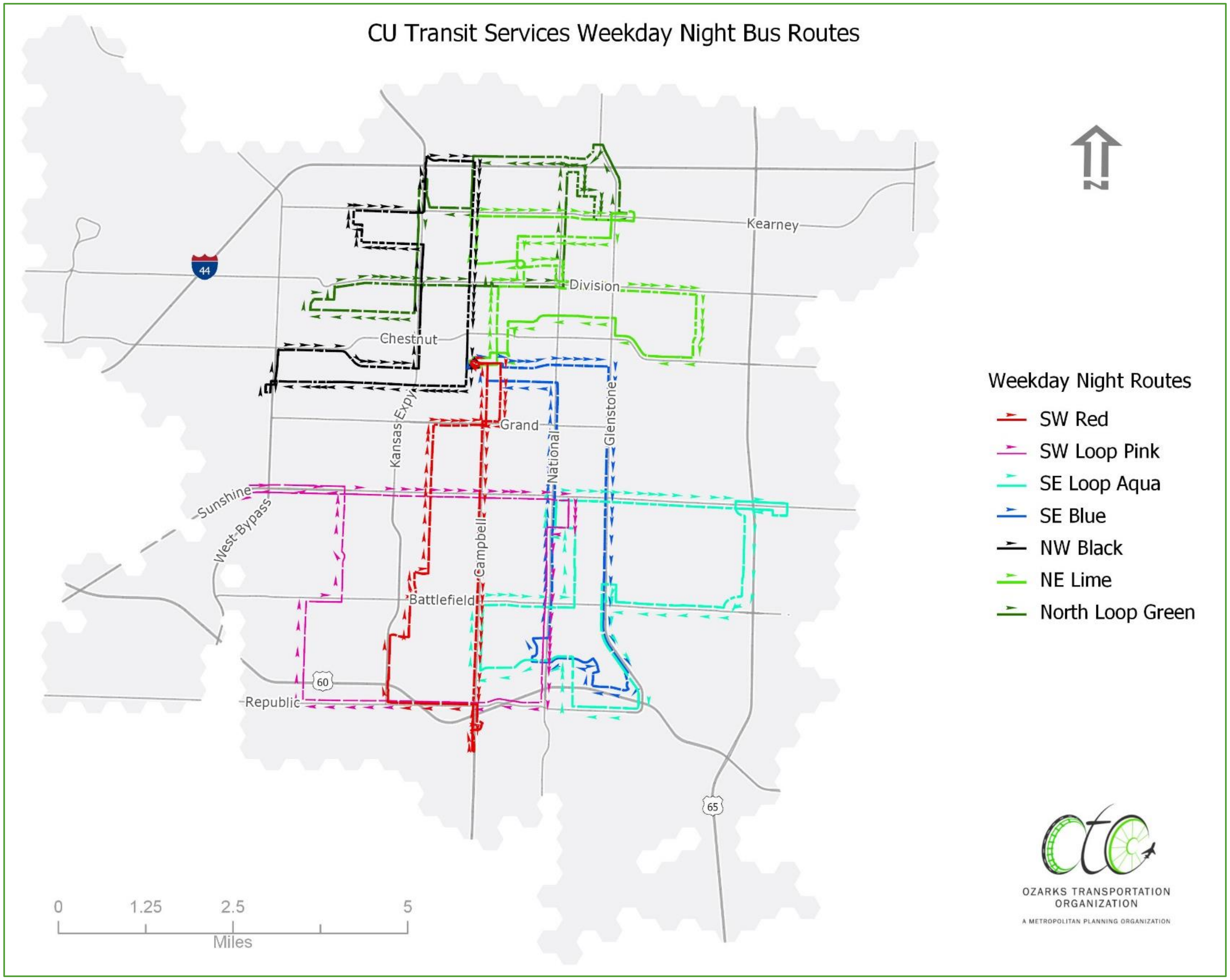

Figure 3: Map of CU Transit Services Weekday Night Routes

PREPARING THE DATA

After framing the questions for the analysis, the next step is to explore and prepare the data needed to address the questions. A network dataset for routing is needed for geoprocessing in the Network Analyst extension. Participating features for the multimodal network of greenways, sidewalks, local streets, and bus routes to simulate pedestrian and transit travel on in the CU Transit service area were added to a feature dataset from which the network dataset would be built.

A routing network for local streets used for 911 emergencies for first responders in Greene and Christian counties was provided to the OTO by the City of Springfield GIS department. The file included the OTO Major Thoroughfare Plan (MTP) street classifications, elevation fields to simulate bridges, one-way streets, and length. The OTO maintains feature classes for greenways and sidewalks for its study area. To connect these features in a multimodal dataset, point files of nodes were created to represent the linkages between greenways, streets, and sidewalks to allow pedestrian movement across different features. The connecting nodes were added to the same feature dataset as the other participating features in preparation of adding GTFS data for bus routes and stops.

The toolset for adding GTFS to a network dataset were downloaded and installed the from the Esri public transit tools page at GitHub. GitHub is a code hosting platform for version control and collaboration. The installation registers a transit evaluator with ArcGIS that allows a network dataset to query GTFS schedules when determining travel time through a network and adds "Add GTFS to a Network Dataset" and "Transit Analysis Tools" toolboxes to ArcToolbox. In the Add GTFS to a network dataset toolbox are tools for 1) generating transit lines and stops, 2) generating stop-street connectors, and 3) getting network EIDs.

The first tool adds transit lines and stops to the feature dataset where the other participating features in the network dataset are stored. The second tool snaps connector lines and nodes to transit stops creating connectivity to transit lines from streets or sidewalks. The third tool is run after the network dataset is built for the transit evaluator to query stop times in a SQL database that was created when the first tool was run.

The multi-modal network dataset is created using the network dataset wizard in ArcMap. The wizard is only available with the Network Analyst license. In the wizard, features for different modes that participate in the network are assigned to connectivity groups, travel time attributes for walking are set, and restrictions for travelling on some features are assigned. A cost attribute for the time in minutes to travel along pedestrian facilities was created for a walking speed of 3.1 mph. The street network file was used with a restriction preference for local, collector, and secondary arterial street classes and connected to greenways to route pedestrians to transit stops. Figure 2 on page 5 depicts elements of the network dataset.

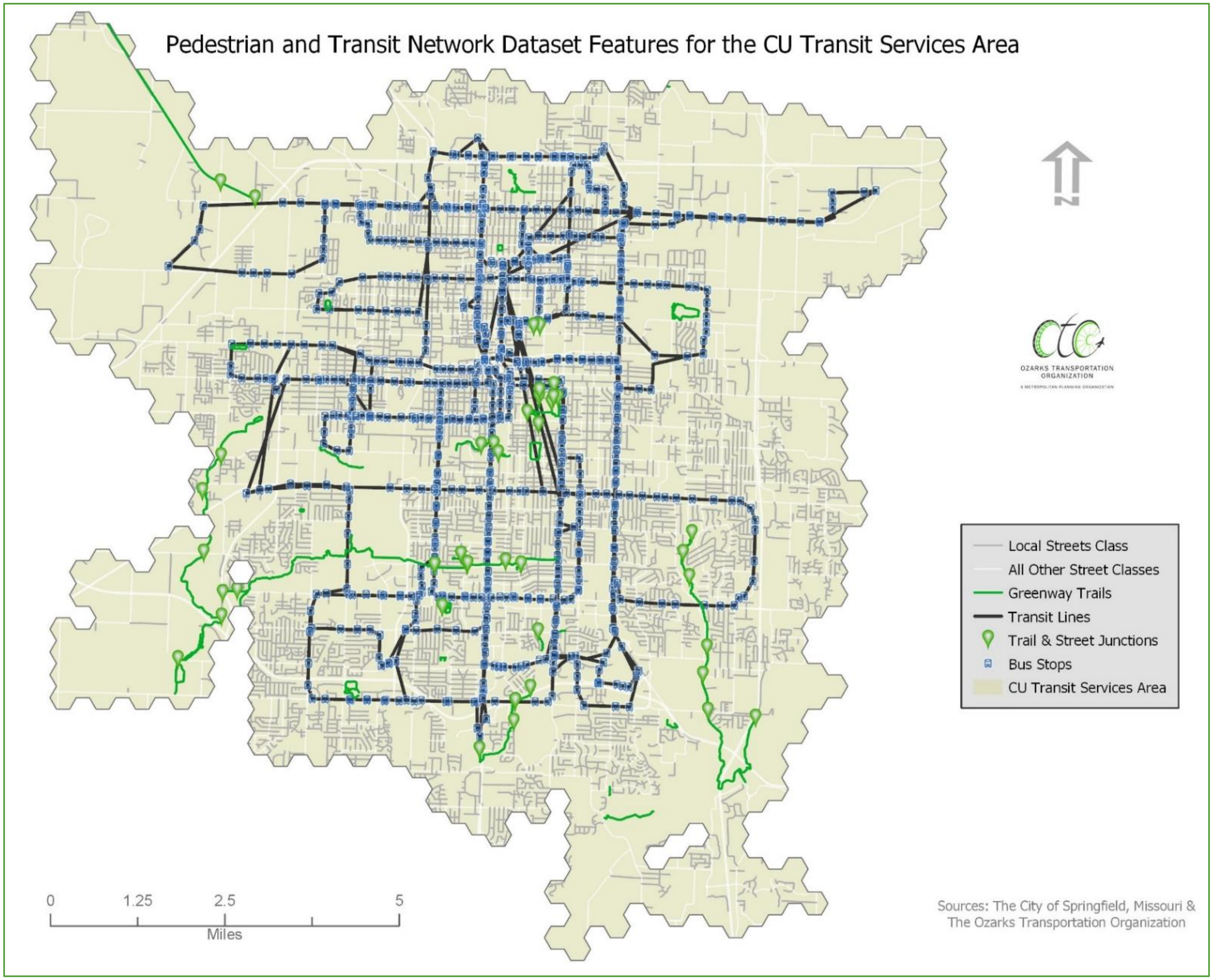

Figure 4: Multimodal Network Dataset Features

ArcGIS Online Living Atlas layers are authoritative geographic features hosted by Esri and accessed via a cloud portal. Esri has developed demographic profiles at the census block group level as well as other consumer habit and marketing segment features for use in its Business Analyst extension. One of the Business Analyst layers contains 2018 population estimates. Additional layers include daytime population estimates. This estimate counts the people added to an area during the daytime for work or other activities while subtracting resident population that have left the area for work or other activities. A net positive change in daytime population from the resident or nighttime population represents the activity centers where people are going within the CU Transit Services area during the day.

In addition to Living Atlas layers, Esri also hosts geoprocessing tools in the cloud. One of these tools is the enrich layer tool. This tool allows you to overlay geographic features onto other layers and enrich the overlaying features with information from the other layer. The output is a duplicate of your input with additional attribute fields summarized from the underlaying features. The enrich tool uses a geographically weighted census block centroid method to allocate demographic data at scales smaller than census block groups [8].

A grid of 1,178 one/tenth square mile hexagons was constructed to overlay the approximately 100 square mile CU Transit Services area upon the Living Atlas layer for Daytime Population and enrich with daytime and resident population estimates within each hexagon in the grid. There were 328 hexagon polygons with a positive net change in daytime population from the resident population which were converted to point features to use as destination locations for OD cost matrices in Network Analyst.

The method for estimating 2018 population and socio-economic characteristics for census blocks was developed using the hexagon layer enriched with the Esri 2018 population estimates, the 2010 census block summary file population and household characteristics, and geocoded building permits for housing unit construction maintained by the OTO for 2011 through 2017. Geocoded housing unit construction permits from 2011 – 2017 was aggregated by census blocks. Adding this count to the 2010 total housing units yielded an updated total of housing units for census blocks as of January 1, 2018.

The percent of occupied housing units for census block groups from the 2012 – 2016 ACS Five-Year Estimates was applied to the updated housing units value for coincident census blocks to estimate occupied units at the block level. The estimated occupied housing units value was multiplied by the 2010 census block average household size to estimate the 2018 population for census blocks. The Summarize Within tool was used to total the 2018 population census block estimates for the grid of hexagons to compare with the Esri demographic 2018 population estimates. When summarized by hexagon, the estimated 2018 census block population totaled 204,560 compared to the total of 203,689 for the enriched Esri demographic estimates for a difference of 0.427%. This percentage was subtracted from all census blocks to match the sum for 2018 Esri estimates.

The method for joining 2012 – 2016 ACS Five-Year estimate percentage values to census blocks, such as using percent occupied housing units to estimate 2018 population was used to estimate many other socio-economic variables at the census block level. For example, 2016 estimates of age group percentages for working age people and census block group labor force participation rate estimates were used to calculate the number of workers in each block. Similarly, the percentages of industry sector employment were used to estimate the number of people that work in various industries for each census block.

Other variables that were derived from the 2018 census block population estimates and 2012 – 2016 ACS Five-Year estimates included:

- Total 2018 Population
- Number of Workers
- People Living in $0 to $24,999 Income Households
- People Living in $25,000 to $49,999 Income Households
- People Living in $50,000 to $74,999 Income Households
- People Living in $75,000 and greater Income Households
- Number Employed by Industry
- Means of Transportation to Work
- Travel Time to Work
- Time Leaving for Work
- Number of Household Vehicles Available

The census block centroids were used as the origin locations in OD cost matrices which were used to measure access via transit to the hexagon destination points. Figure 4 on page 9 is a map of 2018 population estimates for census blocks summarized by hexagon grid using OTO housing unit permit data and ACS 2012 – 2016 Five-Year estimates. Hexagons with zero population were removed from the grid.

Table 1 on page 11 contains population and socio-economic characteristic estimates for the CU Transit service area.

Figure 6 on page 12 is a map of the 328 area hexagons with a positive net change in daytime population for use as weighted activity centers in the OD matrices. The values for daytime population change were used to calculate a cumulative opportunities accessibility measure described in the Analysis Method and Tools section.

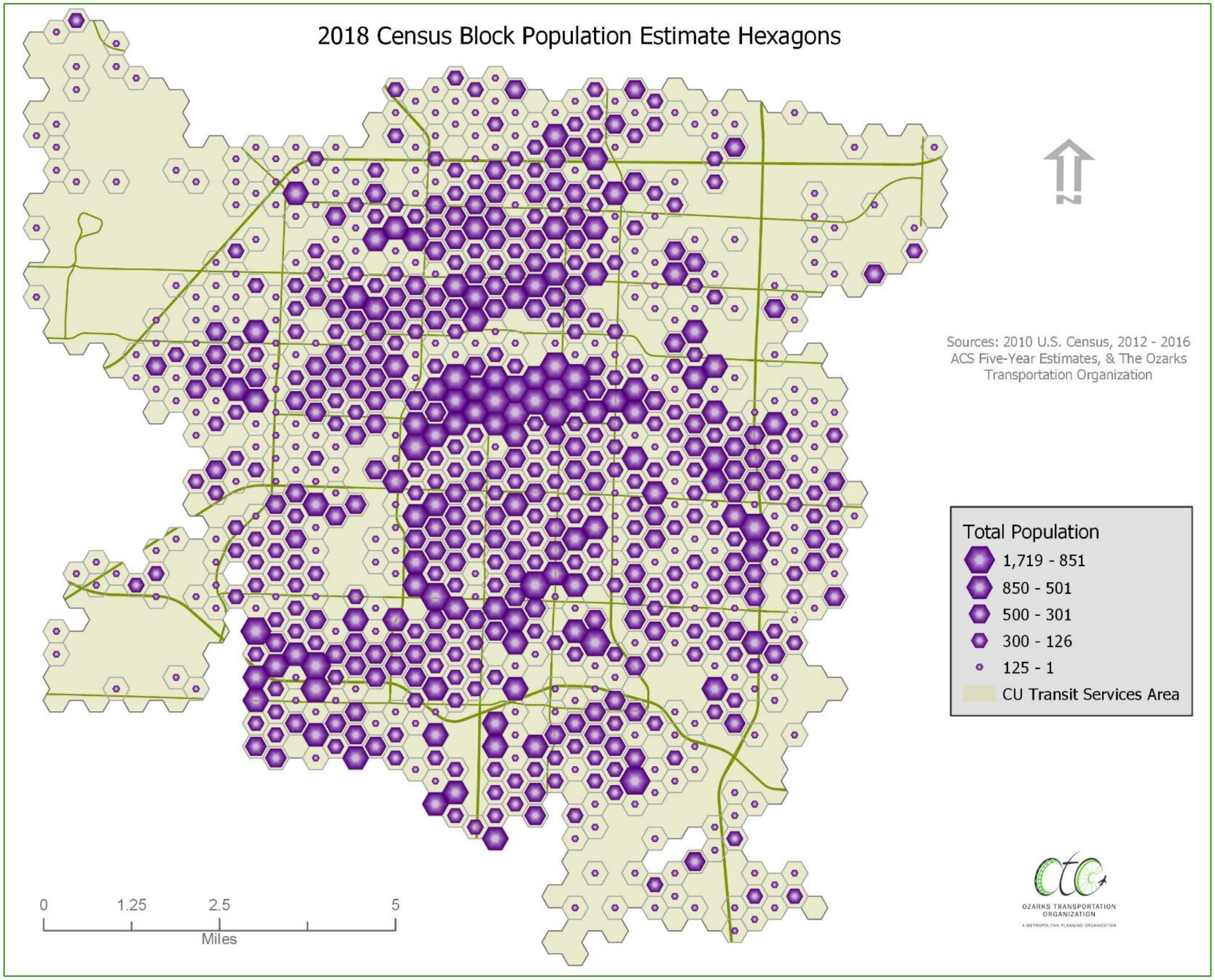

Figure 5: Service Area Hexagons with Census Block 2018 Population Estimates

Table 1: 2018 CU Transit Service Area Population and Socio-Economic Characteristic Estimates

2018 CU Transit Service Area Estimate	Number	%	2018 CU Transit Service Area Estimate	Number	%
Total Pop 2018	203,883		Left for Work 12pm to 3:59pm	9.471	10.6
Total Labor Force 2018	89,339	43.8	Left for Work 4pm to 11:59pm	8,709	9.7
Labor Force Age 29 or Younger	31,840	35.6	Left for Work 12am to 4:59am	2,796	3.1
Labor Force Age 30 to 54	36,852	41.2	Agriculture, Forestry, Mining Labor Force	333	0.3
Labor Force 55 to 69	20,647	23.1	Construction Labor Force	4,163	4.6
Pop living in less than $25,000 Income Households	68,405	33.5	Manufacturing Labor Force	7,273	8.1
Pop living in $25,000 to $49,999 Income Households	61,369	30.1	Wholesale Trade Labor Force	2,590	2.9
Pop living in $50,000 to $74,999 Income Households	52,557	25.7	Retail Trade Labor Force	12,448	13.9
Pop living in $75,000 and greater Income Households	21,503	10.5	Transportation & Warehousing Labor Force	3,951	4.4
Drove Alone to Work	72,243	80.8	Information Labor Force	2,081	2.3
Carpooled to Work	8,894	9.9	Finance & Insurance Labor Force	1,788	2
Public Transit to Work	769	0.8	Real Estate, Rental & Leasing Labor Force	1,788	2
Taxi to Work	140	0.1	Professional, Science, & Technology Labor Force	6,458	7.2
Motorcycle to Work	191	0.2	Management of Companies Labor Force	139	0.1
Bicycle to Work	678	0.7	Administrative Support & Waste Services Labor Force	4,519	5
Walk to Work	2,566	2.8	Education & Social Services Labor Force	8,716	9.7
Other Means to Work	619	0.7	Healthcare Labor Force	14,513	16.2
Worked at Home	3,151	3.5	Art & Entertainment Labor Force	1,538	1.7
Pop Living in 0 Vehicle Households	16,136	7.9	Accommodation & Food Service Labor Force	9,523	10.6
Pop Living in 1 Vehicle Households	86,800	42.5	Other Services Labor Force	4,736	5.3
Pop Living in 2 Vehicle Households	73,572	36	Public Administration Labor Force	2,533	2.8
Pop Living in 3 plus Vehicle Households	27,182	13.3	Less than 5 minutes to Work	3,016	3.3
Left for Work 5am to 5:29am	2,053	2.3	5 to 9 minutes to Work	11,545	12.9
Left for Work 5:30am to 5:59am	3,592	4	10 to 14 minutes to Work	19,656	22
Left for Work 6am to 6:29am	4,707	5.2	15 to 19 minutes to Work	23,623	26.4
Left for Work 6:30am to 6:59am	7,524	8.4	20 to 24 minutes to Work	15,939	17.8
Left for Work 7am to 7:29am	11,943	13.3	25 to 29 minutes to Work	4,403	4.9
Left for Work 7:30am to 7:59am	14,253	15.9	30 to 34 minutes to Work	5,939	6.6
Left for Work 8am to 8:29am	10.047	11.2	35 to 39 minutes to Work	559	0.6
Left for Work 8:30am to 8:59am	3,794	4.2	40 to 44 minutes to Work	606	0.6
Left for Work 9am to 9:59am	5,156	5.7	45 to 59 minutes to Work	1,510	1.7
Left for Work 10am to 10:59am	3,414	3.8	60 to 89 minutes to Work	1,100	1.2
Left for Work 11am to 11:59am	1,717	1.9	More than 90 minutes to Work	1,100	1.2

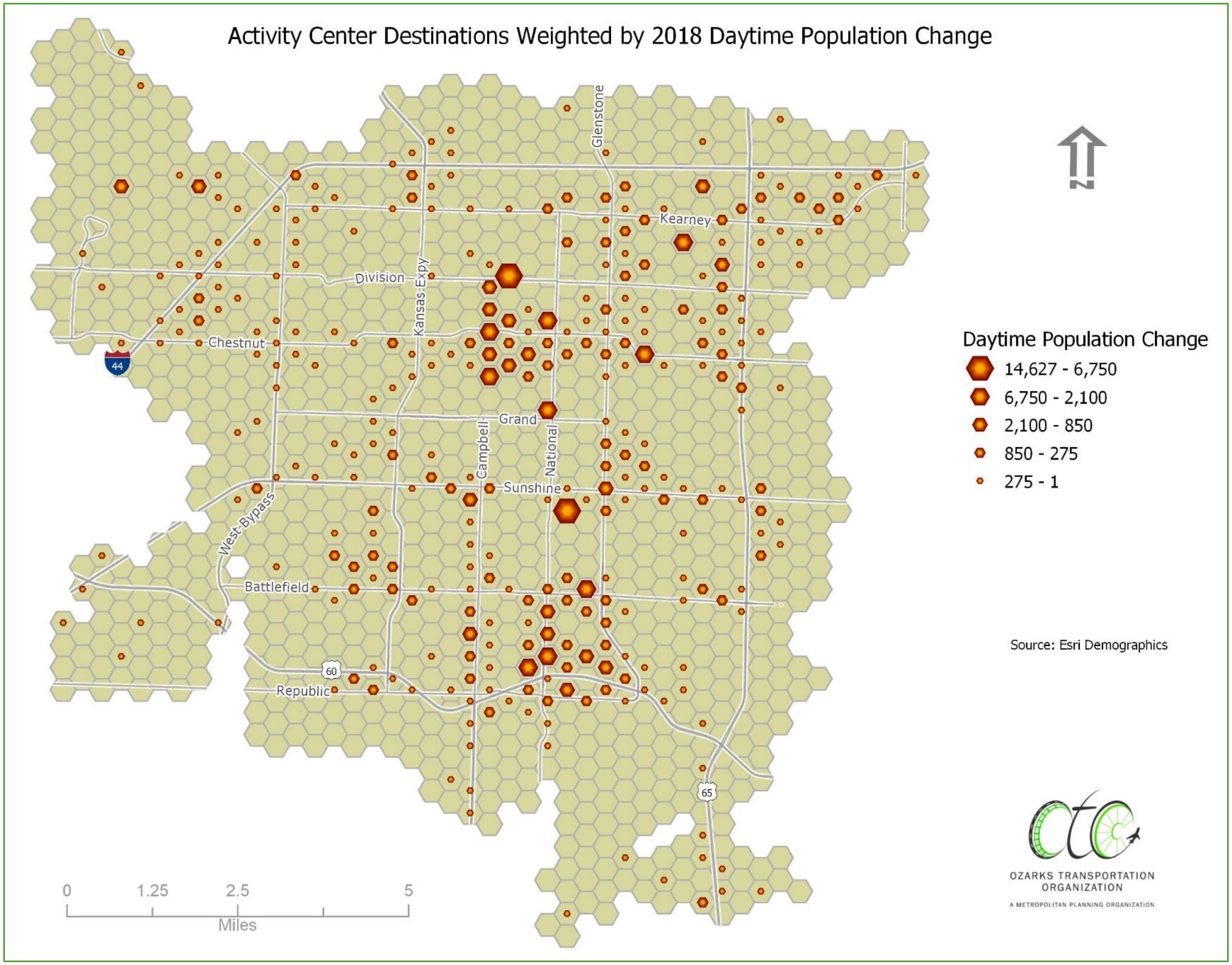

Figure 6: Destinations Weighted by Esri Daytime Population Change

The supplemental Transit Analysis Toolbox contains tools to use with the transit network dataset created with the Add GTFS to a Network Dataset toolset. The Transit Analysis Toolbox includes the following script tools for network analysis using transit:

- Calculate Accessibility Matrix
- Prepare Time Lapse Polygons

The Calculate Accessibility Matrix tool was used to calculate the accessibility measure for this analysis. This tool accounts for the time that buses are scheduled to arrive at transit stops along individual routes. An OD cost matrix was solved at one-minute intervals over the course of a one-hour time window. The tool counts the number of destinations reachable at least once during the time window. The output also shows the number and percentage of destinations reachable for the number of departures times from 10% to 90% of the time over the duration of the time window. These values are added to the attribute table of the original features loaded as origins to run the tool. In this case, the origins were the 3,676 census block centroids with the estimated socio-economic census variables.

A Network Analyst service area layer generates polygons depicting the area reachable to or from locations within a time threshold on a transportation network. The Create Time Lapse Polygons creates service area polygons for a set of point locations for each minute during a time window. A service area can be very different one minute after the bus departs from a stop location limiting the area to walking distance alone.

Figure 7 on page 14 depicts the time variability of service area polygons for a location in the southwest part of the CU Transit Services area within a 30-minute cutoff.

An additional toolset designed to count the bus trips around stops uses GTFS files as input and travel time parameters from a network dataset to create output. Better Bus Buffers pre-prepares GTFS files into a SQL database to use as input for other tools in the toolset [9]. The Count Trips by Polygon Buffers generates polygon service areas based on walking times to stops along routes. The tool then counts the number the number of trips available in the polygons during a time window. The result is a transit coverage map that can be color coded by frequency of service.

Three multimodal network datasets were created to run the analysis tools described in this section. The first network dataset was built by adding the unaltered CU Transit GTFS files to generate output for daytime routes with current schedules. Two more network datasets were built with modified stop times for night routes for 20-minute and 15-minute headways. The results from these processes were used to compare existing weekday daytime routes and schedules to weekday night routes with increased frequency alternatives and investigate changes in accessibility.

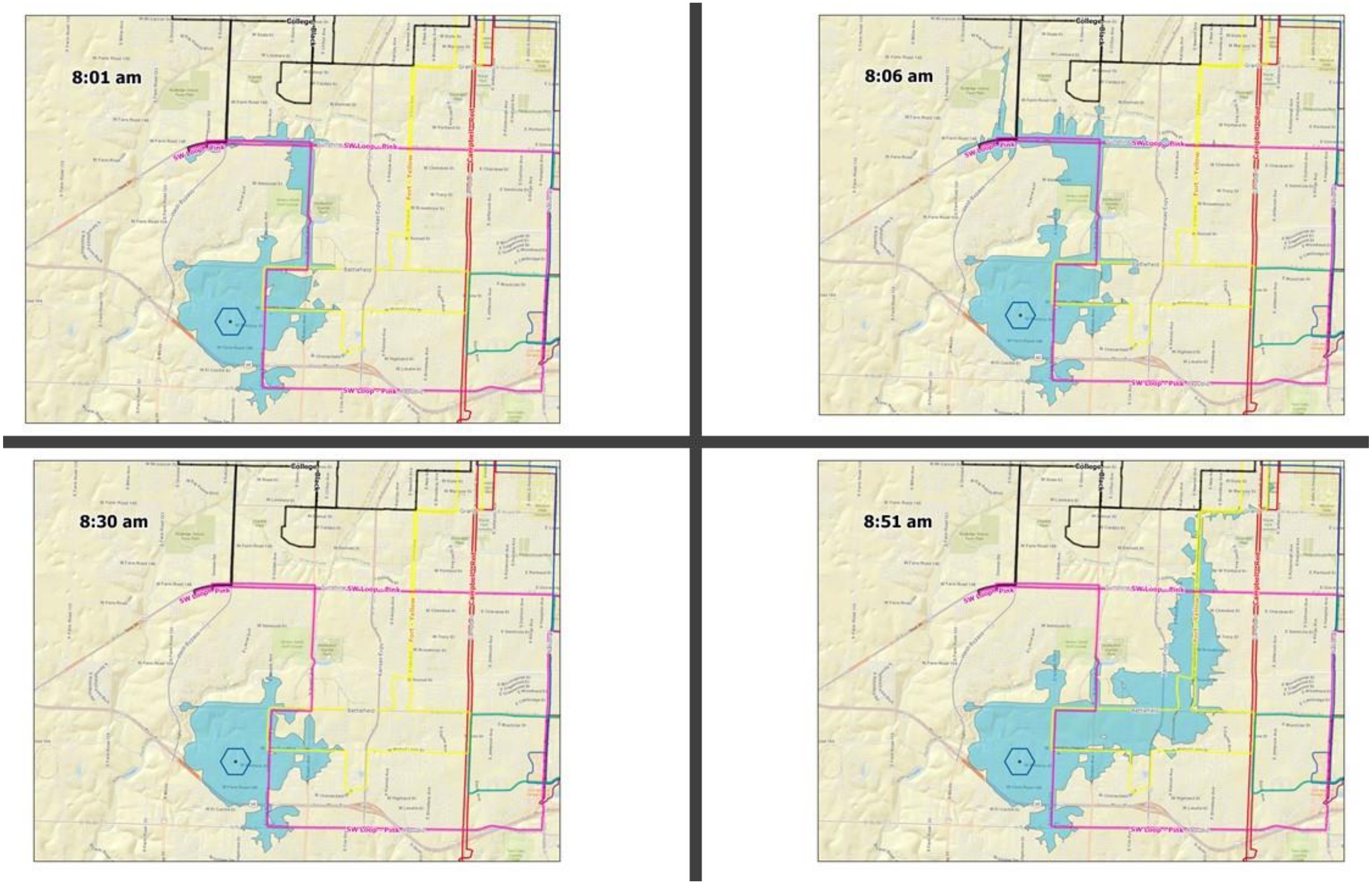

Figure 7: Examples of Service Area Polygon Change for Each Minute of a One-Hour Time Window Using Transit Routes and Stop Times

PERFORMING THE ANALYSIS

Running the Calculate Accessibility Matrix transit analysis tool involves three steps:

- Prepare your origin and destination data
- Prepare an OD Cost Matrix layer to use as input
- Run the Create Accessibility Matrix tool

Preparation of the origin and destination data has been discussed at length in previous sections as well as building the transit network dataset. Once the transit network dataset has been added to ArcMap, a new OD Cost Matrix layer can be added to the map. The layer properties can be set from the Network Analyst window. The cost and restriction attributes configured when the transit network dataset was built are enabled from the Analysis Settings tab. A cutoff of 60 minutes was set in the "Default Cutoff Value" box. Once the analysis settings were configured the layer was used as input for the tool.

Tool Inputs

- OD Cost Matrix Layer: configured OD Cost Matrix in ArcMap or saved as .lyr file
- Origins: Census Block centroids
- Destinations: Enriched Positive Daytime Population Change Hexagon centroids
- Destinations Weight Field: DayPopDelta
- Start Day: Generic weekday
- Start Time: 08:00
- End Day: Generic weekday
- End Time: 09:00
- Time Increment (minutes): 1

Tool Output

These fields are added to the Origins input table:

- TotalDests: The total sum of the weight field for reachable Destinations within the cutoff time
- PercDests: This is Total Dests divided by the summed weights of all Destinations
- DsAL10Perc, DsAL20Perc,..., DsAL90Perc: These fields represent the total number of Destinations reachable by this origin within the cutoff at least x% of Start Times in the time window, where x is the number in the field name (10,20,...,90).
- PsAL10Perc, PsAL20Perc,..., PsAL90Perc: These are companion fields to DsAL10Perc, etc. and have the same relationship to PercDests does to TotalDests

Destinations not reachable a higher percentage of times will not contribute their weight to those fields. For example, if Destination 1 can only be reached by origin A within the time limit 9 of the 60 start times, or 15% of the time, the weighted value will be added to DsAL10Perc but not DsAL20Perc. Figure 8 depicts the diminishing percent of destination weights reachable on weekday daytime routes for, 20%, 50%, 70% and 90% of departure times, respectively. The measure used for this study is the total and percent for 90% of departure times.

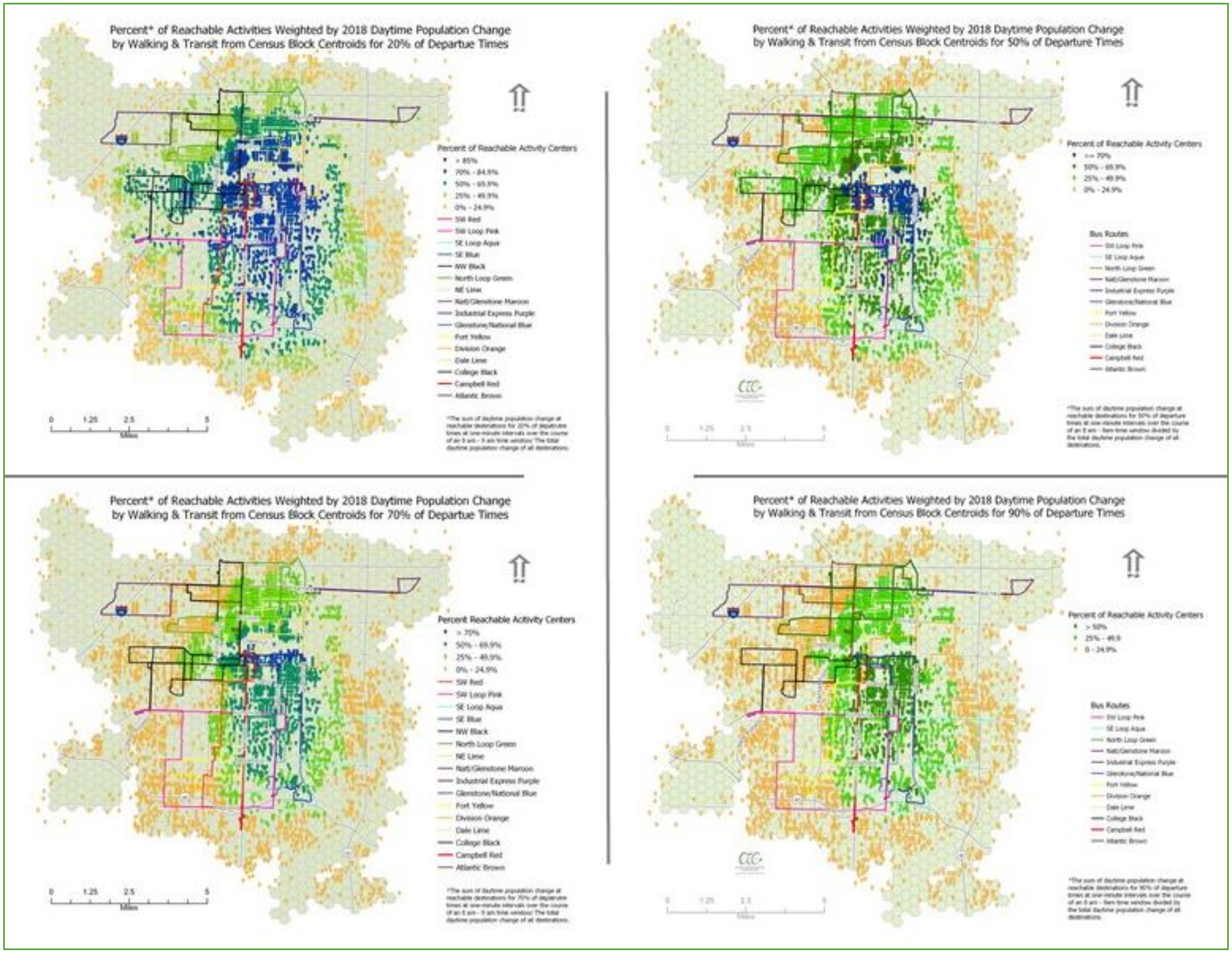

Figure 8: Percent of Destination Weights Reached for Percentage of Departure Times During a One-Hour Time Window

Running the Prepare Time Lapse Polygons tool involves three steps:

- Prepare Service Area layer in ArcMap
- Run the Prepare Time Lapse Polygons tool
- Create a time lapse video in ArcGIS Pro or ArcMap

Preparation of the Service Area layer in ArcMap is done once the transit network dataset has been added to ArcMap. A new Service Area layer can be added to the map from the drop down on the Network Analyst toolbar. Calculating a service area in Network Analyst creates a polygon representing the area that can be reached for either a distance or travel time. The Prepare Time Lapse Polygons tool solves a service area for a range of start times and saves the polygons as an output feature class. The Service Area layer properties can be set from the Network Analyst window. The cost and restriction attributes configured when the transit network was built are enabled from the Analysis Settings tab. A travel time of 30 minutes was set in the "Default Breaks" box. Once the analysis settings were configured the layer was used as input in the tool. The 804 CU Transit Services area populated hexagon centroids were loaded as facilities into the Service Area layer settings prior to running the tool.

Inputs

- Service Area Layer: The ready to solve Service Area layer created in ArcMap
- Output Polygons Feature Class: The feature class containing 49,044 polygons generated by the tool
- Start Day: Generic weekday
- Start Time: 08:00
- End Day: Generic weekday
- End Time: 09:00
- Time Increment (minutes): One minute

Output

- The output polygons feature class containing one row per facility service area for each start time in the one-hour time window

The output from this tool can be used to create a time lapse video of changing service areas at certain locations over the course of the time window. A video was made for the location in Figure 7. In addition, the time lapse polygons are also input for running the Create Percent Access Polygon tool. The tool's Python script was not available with the download however, a work-around summarizing the number of polygons that intersected with each destination point for each minute during the time window was conducted to measure the accessibility to activity centers within the CU Transit Services area. Figure 13 on page 21 is a map of the activity centers by frequency of access via the 30-minute service areas of the 804 populated hexagon centroids for weekday daytime routes.

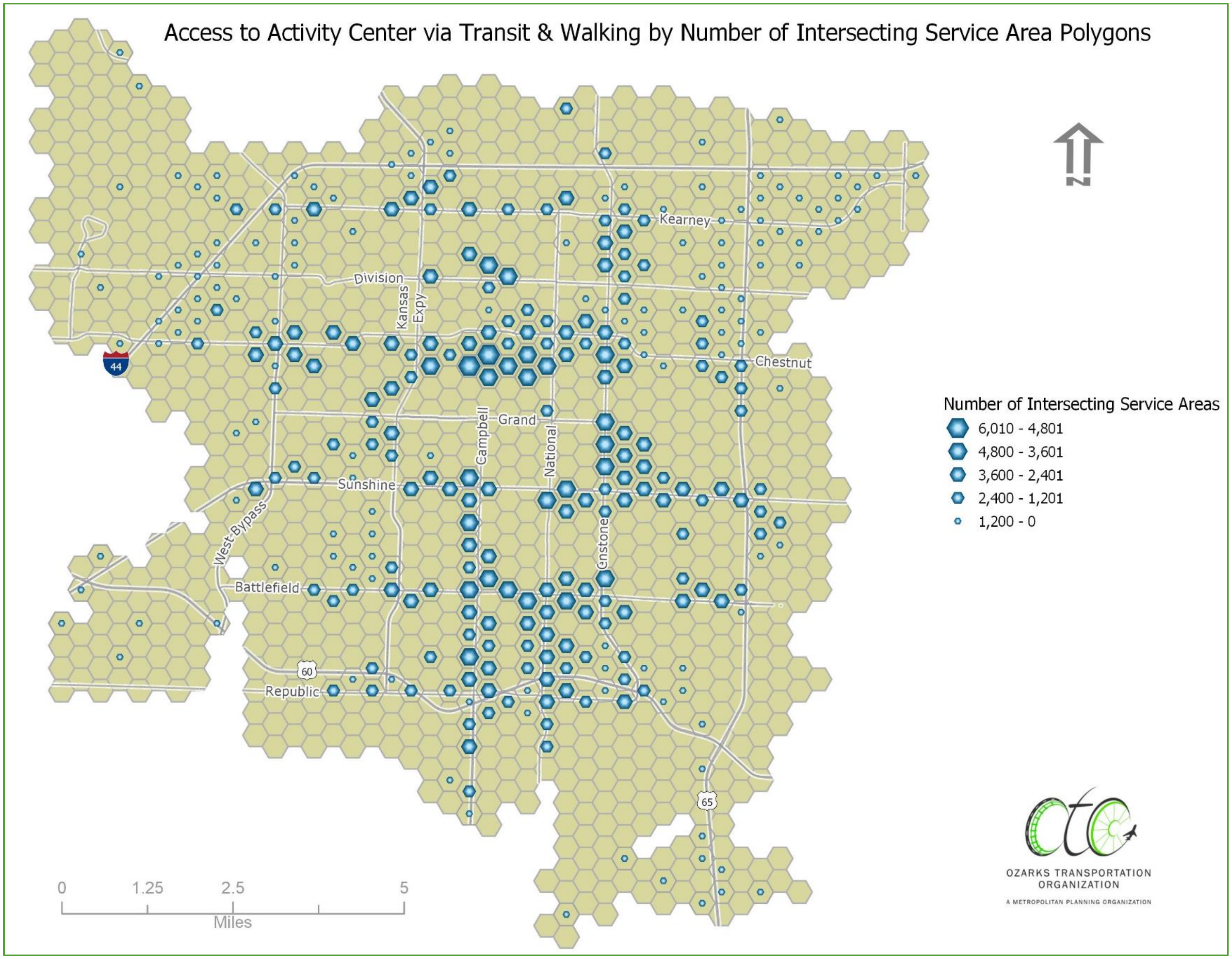

Figure 9: Destination Accessibility by the Total Number of Service Area Polygons from Populated Hexagon Centroids in the Service Area

Running the count trips in polygons tool contains two parts 1) Preprocess Buffers, and 2) Count Trips in Buffers.

The inputs for step one include:

- **Output directory**: A folder where the output geodatabase is saved
- **SQL database of preprocessed GTFS data**: Created with the preprocess GTFS tool
- **Network dataset**: A network dataset of streets, sidewalks, etc.
- **Impedence attribute**: The travel time cost attribute for walking speed
- **Buffer size**: In the same unit as the impedance attribute (10 minutes)
- **Network restrictions**: Preference for lower classed roads

Step one outputs include:

- **Step1_Stops**: A feature class version of the stops.txt GTFS file
- **Step1_FlatPolys**: The service area polygon buffers for the network broken up to to eliminate overlaps

The inputs for step 2 include:

- **Step 1 results geodatabase**: In the output directory from step 1
- **Output feature class**: The name and location for the final output polygons
- **Weekday or YYYYMMDD date**: Generic weekday
- **Time window start**: 08:00
- **Time window end**: 08:59
- **Count arrivals or departures**: Departures

Step two output feature class attributes:

- **NumTrips**: The total number of unique transit trips accessible in the service area polygon location
- **NumTripsPerHr**: NumTrips divided by the length of the time window
- **NumStopsInRange**: The number of transit stops accessible to the polygon location
- **MaxWaitTime**: The maximum wait time in minutes between consecutive transit trip departures during the time window

Figure 10 on page 20 compares the color-coded frequencies of transit trips for daytime routes and nighttime route alternatives. The frequency intensity is the greatest for night route polygons with 15-minute headways

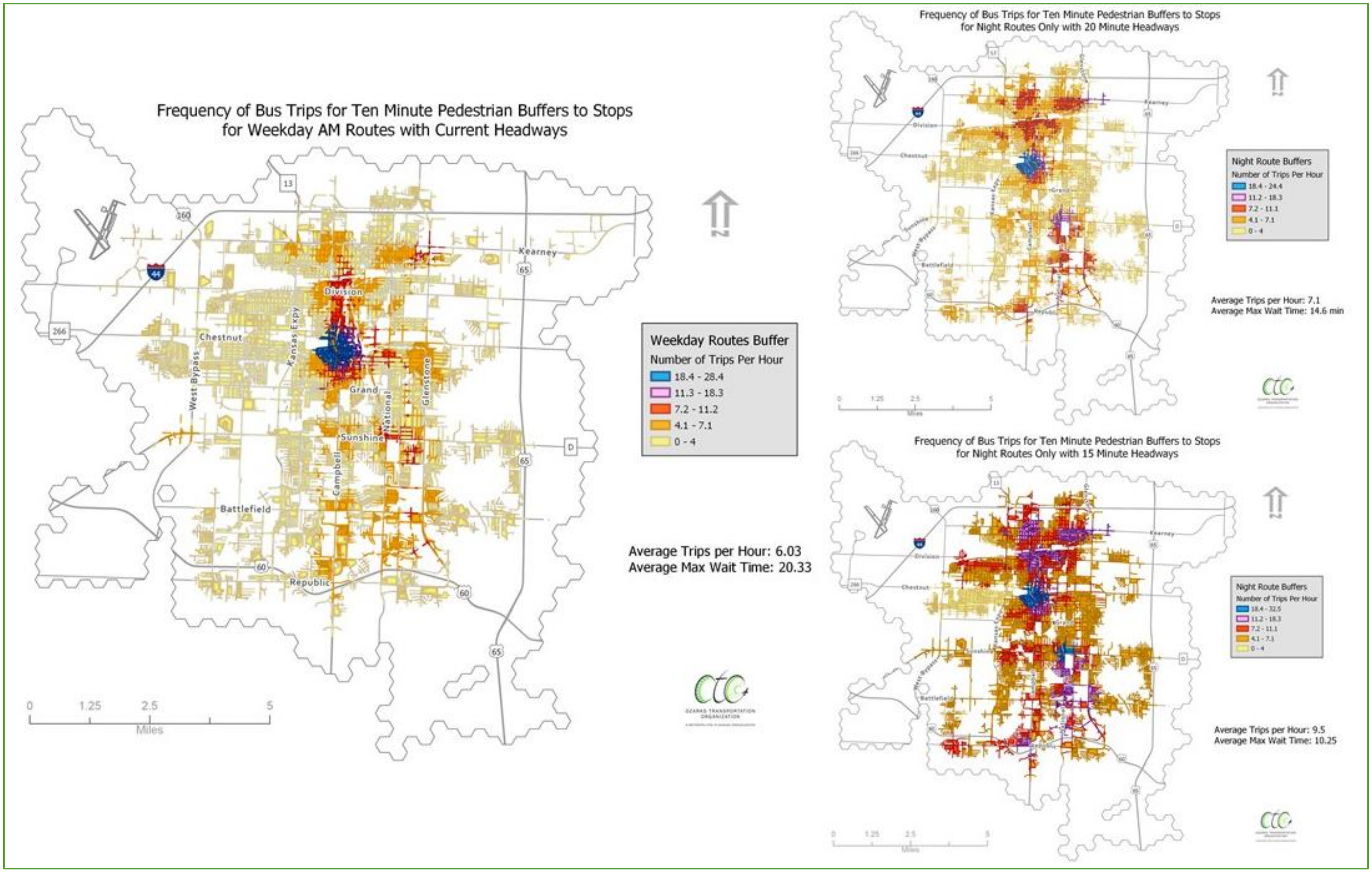

Figure 10: Frequency of Bus Trips for Ten Minute Polygons for Daytime Routes and Nighttime Alternatives

The results of the OD cost matrices for the percent of weighted destinations reached for 90% of departure times were aggregated for the 825 hexagon polygons containing population and demographic estimates to compare changes in accessibility. Figures 11, 12, and 13 on pages 22, 23, and 24 are maps of the percent of destination weights reached for weekday day bus routes, weekday night routes with 20-minute headways, and weekday night routes with 15-minute headways, respectively.

Figure 14 on page 25 is a map of very low transit accessibility and low-income areas in the CU Transit Service area for existing weekday daytime routes and schedules. Very low transit accessibility is defined as 10% or less of the total destination weights reached during 90% of the departure times in the time window. Low-income areas are defined as those that have more than the total area average of people living in households with lower than $25,000 in annual income (33.5%).

The percentage of people living in zero car households increased significantly from 7.1% or 862 people to 11.7% or 3,030 people when the percentage of destination weights reached was increased to 20%, which is slightly above the area average, during 90% of departure times in the time window.

Figure 15 on page 26 is a map depicting the 2018 population living in zero car households at the census block level for low transit accessibility (20%) and low-income areas.

Population characteristics were used to summarize population attributes for areas with the highest increases and decreases in accessibility to activity centers when comparing the results from the three route scenarios. The upper and lower 12% of the 825 populated hexagon polygons were used to describe the winners and losers by the change in the number of total of destination weights reached when comparing the night route alternatives to the existing weekday daytime routes and schedules.

Figure 16 on page 27 is a map of the change in the sum of destination weights reached for 90% of departure times between existing weekday day bus routes and weekday night routes with 20-minute headways. Table 2 on page 28 is a summary of population characteristics for the upper 12% of hexagons that had an increase in accessibility. Table 3 on page 29 is a summary of population characteristics for the lower 12% of hexagons that had a decrease in accessibility. The percentages in the tables are compared to the percentages for the entire service area presented in Table 1 on page 11.

Figure 17 on page 30 is a map of the change in the sum of destination weights reached for 90% of departure times between existing weekday day bus routes and weekday night routes with 15-minute headways. Table 4 on page 31 is a summary of population characteristics for the upper 12% of hexagons that had an increase in accessibility. Table 5 on page 32 is a summary of population characteristics for the lower 12% of hexagons that had a decrease in accessibility. The percentages in the tables are compared to the percentages for the entire service area presented in Table 1 on page 11.

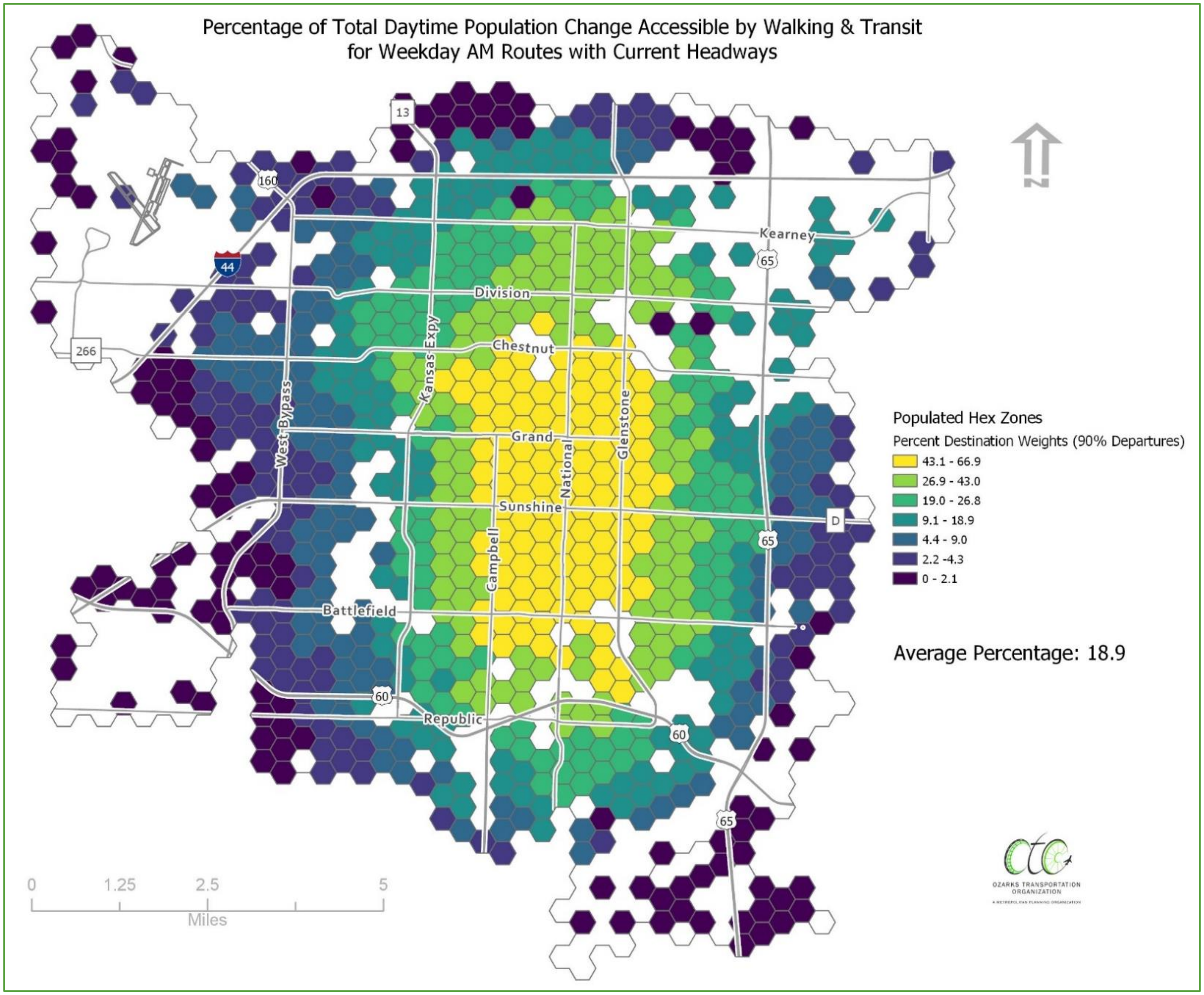

Figure 11: Percentage of Weighted Activity Centers Accessible by Walking & Transit for Weekday AM Routes with Current Headways

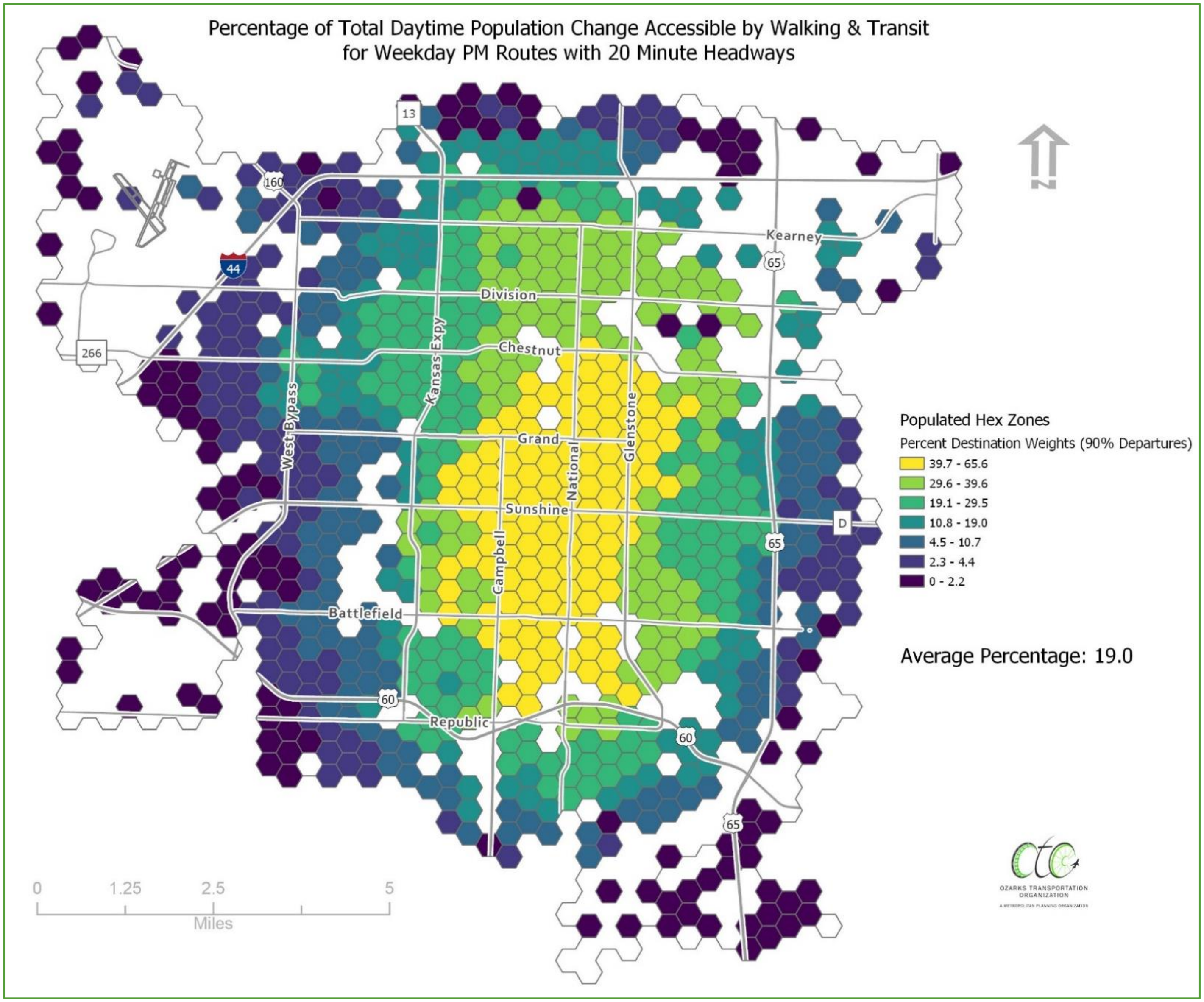

Figure 12: Percentage of Weighted Activity Centers Accessible by Walking & Transit for Weekday Night Routes with 20-Minute Headways

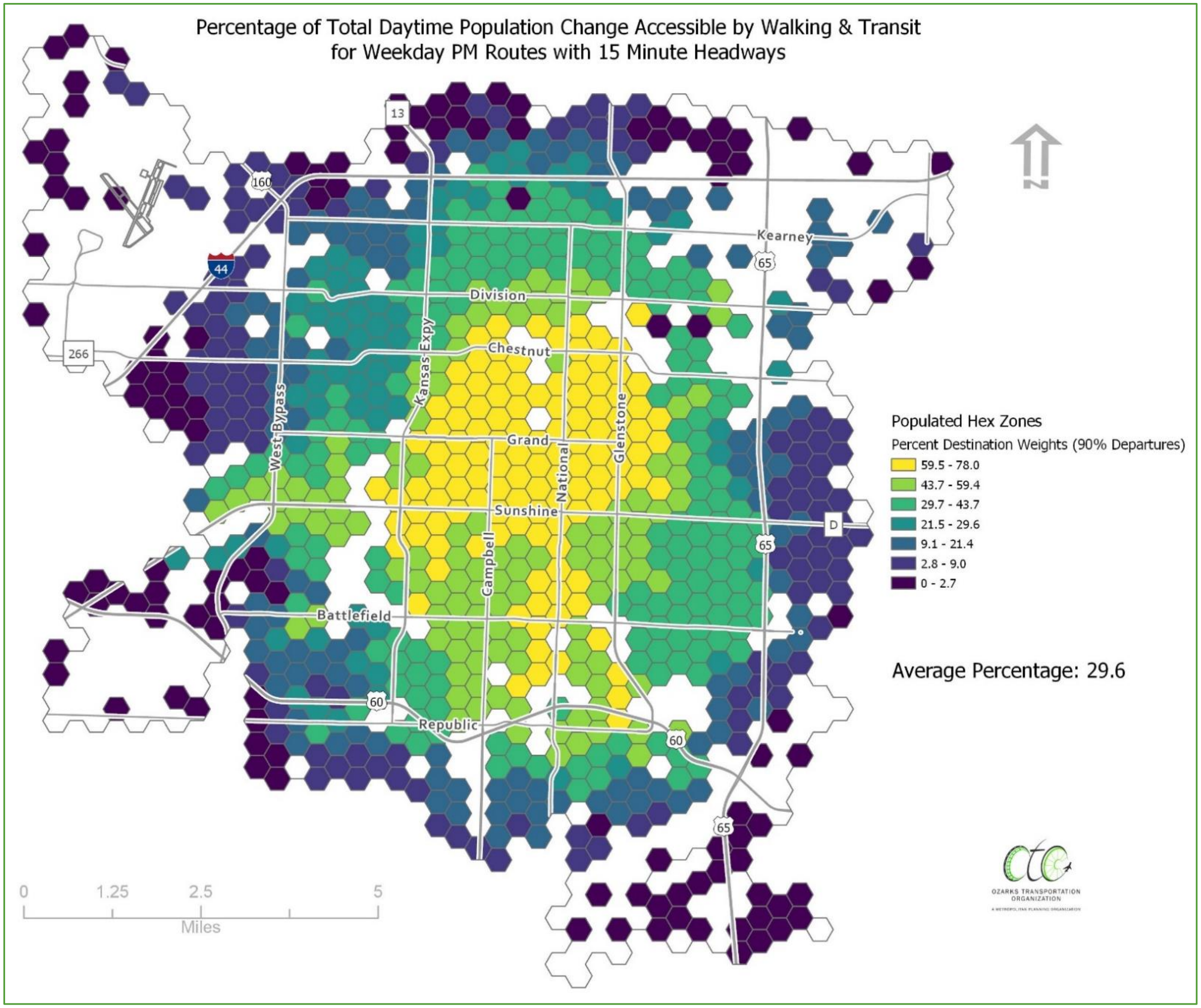

Figure 13: Percentage of Weighted Activity Centers Accessible by Walking & Transit for Weekday Night Routes with 15-Minute Headways

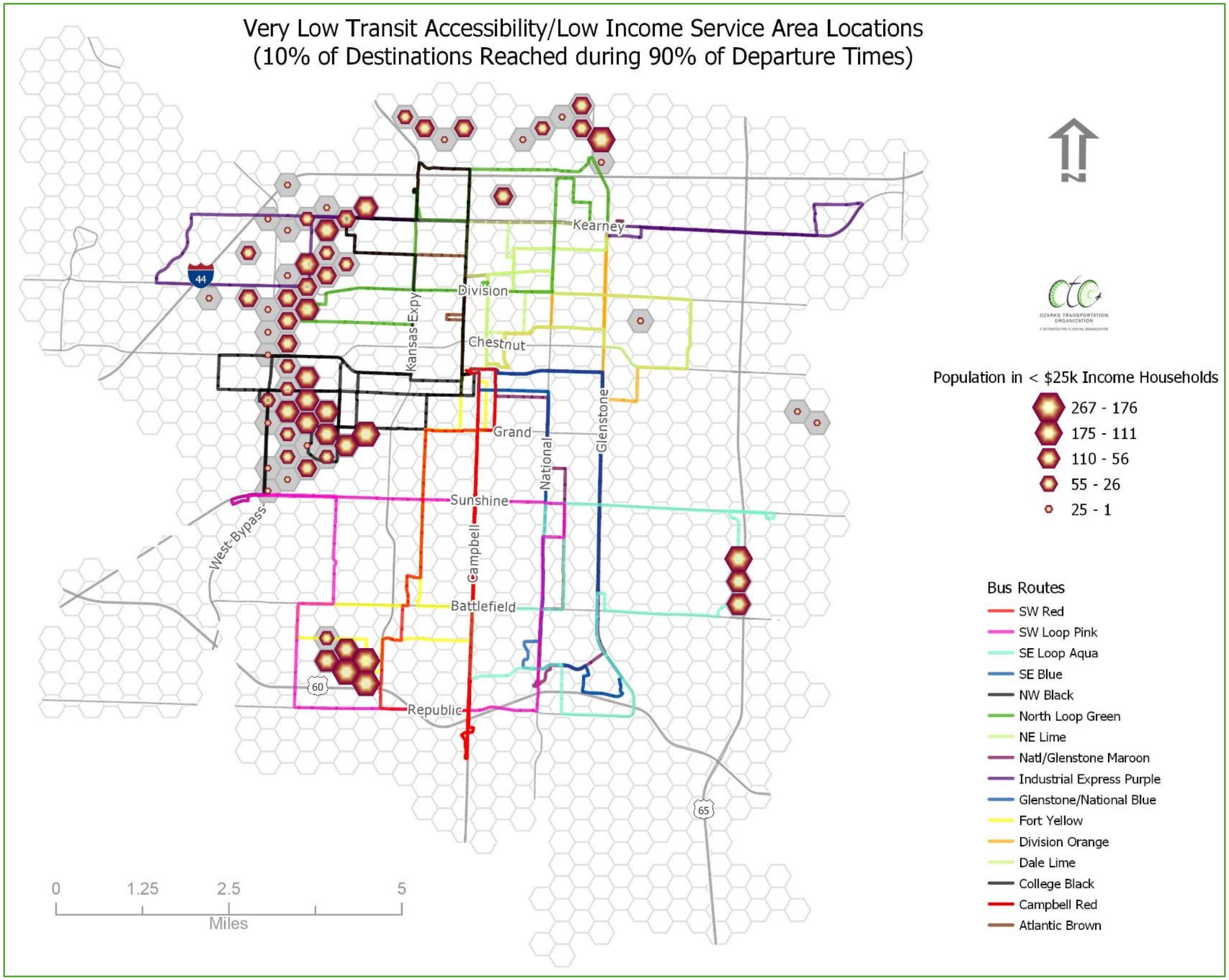

Figure 14: Population in Low Income Households in Locations with Very Low Transit Accessibility for Current Weekday Daytime Routes

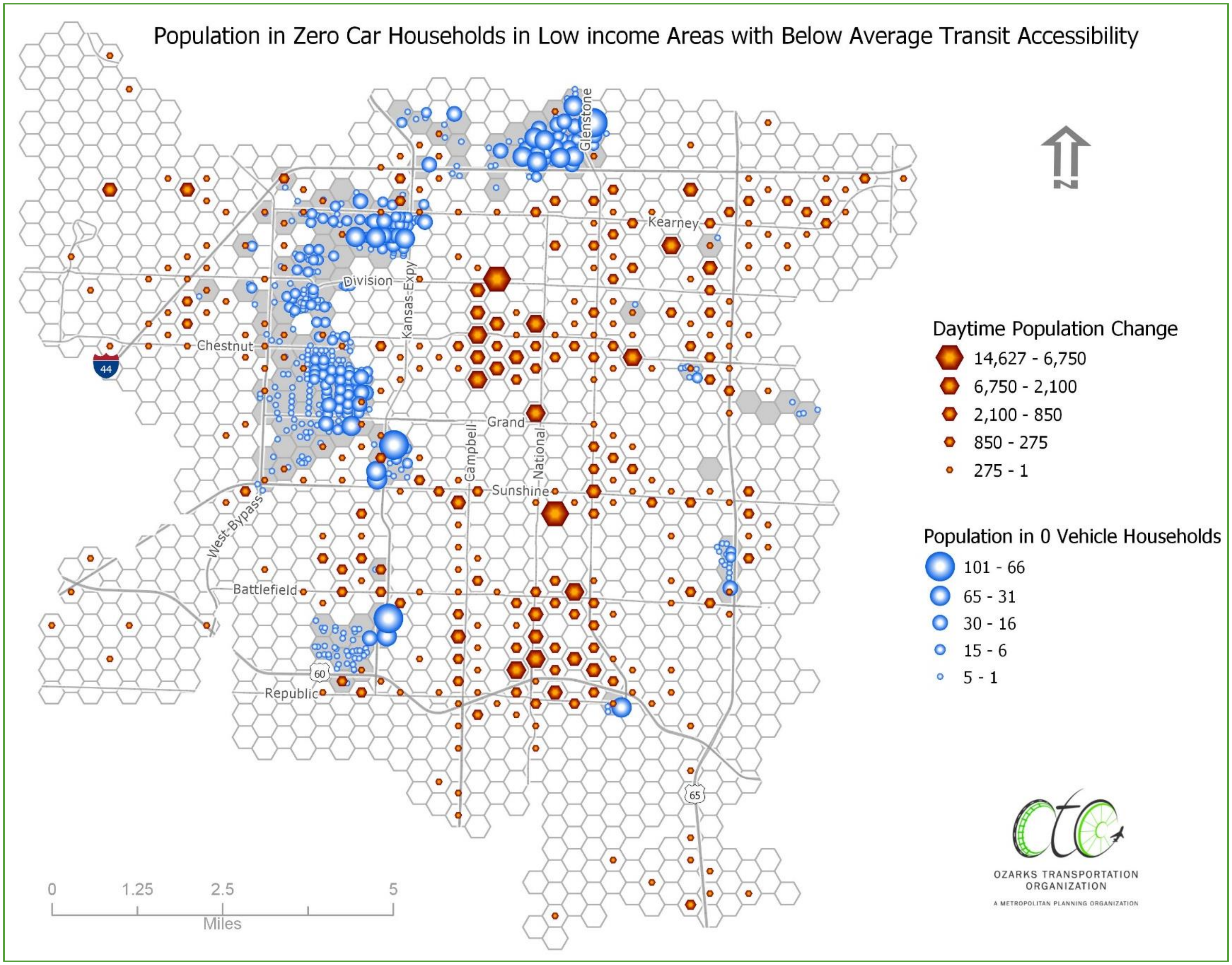

Figure 15: Population in Zero Car Households in Low Income Areas with Average and Below Average Transit Accessibility for Current Weekday Daytime Routes

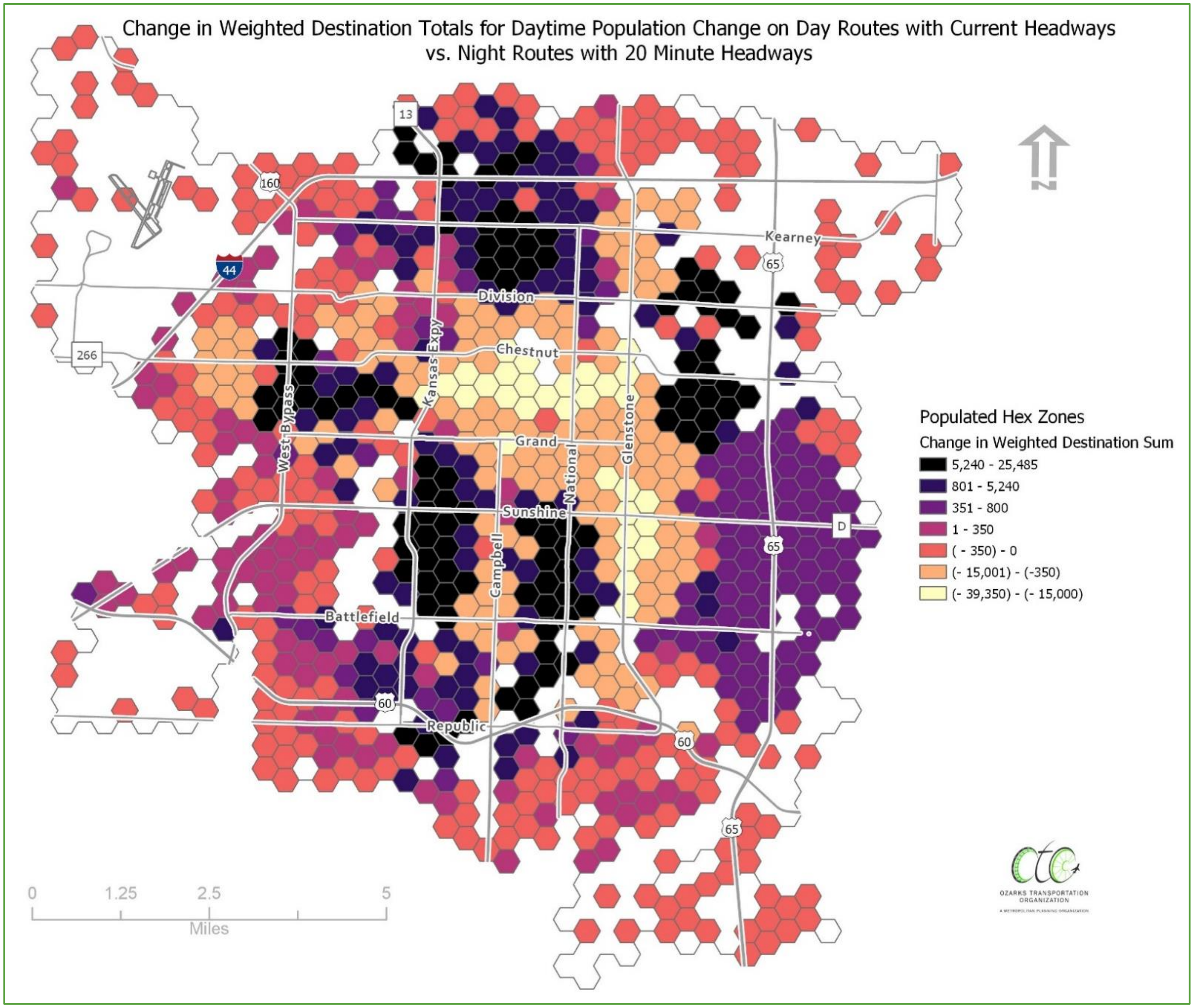

Figure 16: Change in Weighted Destination Sums for Weekday Daytime Routes vs. Night Routes with 20-Minute Headways

Table 2: Estimated 2018 Population Characteristics for Areas with a Change in Weighted Destination Sums Greater than or Equal to 5,000 for Night Routes with 20-Minute Headways

2018 OTO Estimates	Number	%	2018 OTO Estimates	Number	%
Total Pop 2018	29,824	14.6	Left for Work 12pm to 3:59pm	1,110	9.0
Total Labor Force 2018	12,252	41.1	Left for Work 4pm to 11:59pm	1,201	9.8
Labor Force Age 29 or Younger	4,142	33.8	Left for Work 12am to 4:59am	432	3.5
Labor Force Age 30 to 54	5,315	43.3	Agriculture, Forestry, Mining Labor Force	51	0.4
Labor Force 55 to 69	2,795	22.8	Construction Labor Force	597	4.8
Pop living in less than $25,000 Income Households	10,558	35.4	Manufacturing Labor Force	1,037	8.4
Pop living in $25,000 to $49,999 Income Households	10,550	35.3	Wholesale Trade Labor Force	379	3.1
Pop living in $50,000 to $74,999 Income Households	6,963	23.3	Retail Trade Labor Force	1,903	15.5
Pop living in $75,000 and greater Income Households	1,778	6.0	Transportation & Warehousing Labor Force	632	5.1
Drove Alone to Work	10,146	82.8	Information Labor Force	212	1.7
Carpooled to Work	1,159	9.4	Finance & Insurance Labor Force	167	1.3
Public Transit to Work	54	0.4	Real Estate, Rental & Leasing Labor Force	167	1.3
Taxi to Work	68	0.5	Professional, Science, & Technology Labor Force	892	7.3
Motorcycle to Work	4	0	Management of Companies Labor Force	34	0.2
Bicycle to Work	163	1.3	Administrative Support & Waste Services Labor Force	849	6.9
Walk to Work	168	1.3	Education & Social Services Labor Force	951	7.7
Other Means to Work	98	0.7	Healthcare Labor Force	1,948	15.9
Worked at Home	379	3.1	Art & Entertainment Labor Force	159	1.3
Pop Living in 0 Vehicle Households	2,610	8.8	Accommodation & Food Service Labor Force	1,347	11.0
Pop Living in 1 Vehicle Households	13,802	46.2	Other Services Labor Force	532	4.3
Pop Living in 2 Vehicle Households	9,777	32.8	Public Administration Labor Force	405	3.7
Pop Living in 3 plus Vehicle Households	3,633	12.2	Less than 5 minutes to Work	460	3.8
Left for Work 5am to 5:29am	275	2.2	5 to 9 minutes to Work	1,597	13.0
Left for Work 5:30am to 5:59am	805	6.5	10 to 14 minutes to Work	2,687	22.0
Left for Work 6am to 6:29am	703	5.7	15 to 19 minutes to Work	3,122	25
Left for Work 6:30am to 6:59am	873	7.1	20 to 24 minutes to Work	2,167	17.6
Left for Work 7am to 7:29am	1,421	11.6	25 to 29 minutes to Work	674	5.5
Left for Work 7:30am to 7:59am	2,066	16.8	30 to 34 minutes to Work	804	6.5
Left for Work 8am to 8:29am	1,278	10.4	35 to 39 minutes to Work	60	0.4
Left for Work 8:30am to 8:59am	560	4.5	40 to 44 minutes to Work	78	0.6
Left for Work 9am to 9:59am	710	5.8	45 to 59 minutes to Work	268	2.2
Left for Work 10am to 10:59am	449	3.6	60 to 89 minutes to Work	124	1.0
Left for Work 11am to 11:59am	362	2.9	More than 90 minutes to Work	124	1.0

Above the service area percentage

Below the service area percentage

Equal to the service area percentage

Table 3: Estimated 2018 Population Characteristics for Areas with a Change in Weighted Destination Sums Less than or Equal to -3,600 for Night Routes with 20-Minute Headways

2018 OTO Estimates	Number	%	2018 OTO Estimates	Number	%
Total Pop 2018	37,513	18.4	Left for Work 12pm to 3:59pm	2,404	13.3
Total Labor Force 2018	18,052	48.1	Left for Work 4pm to 11:59pm	2,653	14.7
Labor Force Age 29 or Younger	9,221	51.1	Left for Work 12am to 4:59am	534	2.9
Labor Force Age 30 to 54	5,847	32.4	Agriculture, Forestry, Mining Labor Force	50	0.2
Labor Force 55 to 69	2,984	16.5	Construction Labor Force	940	5.2
Pop living in less than $25,000 Income Households	17,566	46.8	Manufacturing Labor Force	915	5.0
Pop living in $25,000 to $49,999 Income Households	10,561	28.2	Wholesale Trade Labor Force	258	1.4
Pop living in $50,000 to $74,999 Income Households	7,108	18.9	Retail Trade Labor Force	2,838	15.7
Pop living in $75,000 and greater Income Households	2,282	6.1	Transportation & Warehousing Labor Force	587	3.3
Drove Alone to Work	13,301	73.7	Information Labor Force	481	2.6
Carpooled to Work	1,634	4.4	Finance & Insurance Labor Force	394	2.2
Public Transit to Work	289	1.6	Real Estate, Rental & Leasing Labor Force	394	2.2
Taxi to Work	28	0.2	Professional, Science, & Technology Labor Force	1,226	6.8
Motorcycle to Work	89	0.5	Management of Companies Labor Force	21	0.01
Bicycle to Work	242	1.3	Administrative Support & Waste Services Labor Force	830	4.6
Walk to Work	1,633	9.0	Education & Social Services Labor Force	2,319	12.8
Other Means to Work	137	0.8	Healthcare Labor Force	2,451	14.0
Worked at Home	689	3.8	Art & Entertainment Labor Force	528	2.9
Pop Living in 0 Vehicle Households	4,830	12.9	Accommodation & Food Service Labor Force	2,580	14.3
Pop Living in 1 Vehicle Households	17,665	47.0	Other Services Labor Force	893	4.9
Pop Living in 2 Vehicle Households	10,972	29.2	Public Administration Labor Force	453	2.5
Pop Living in 3 plus Vehicle Households	4,050	10.8	Less than 5 minutes to Work	978	5.4
Left for Work 5am to 5:29am	276	1.5	5 to 9 minutes to Work	3,270	18.1
Left for Work 5:30am to 5:59am	428	2.3	10 to 14 minutes to Work	3,928	21.7
Left for Work 6am to 6:29am	931	5.2	15 to 19 minutes to Work	4,834	26.8
Left for Work 6:30am to 6:59am	1,210	6.7	20 to 24 minutes to Work	2,478	13.7
Left for Work 7am to 7:29am	1,655	9.2	25 to 29 minutes to Work	619	3.4
Left for Work 7:30am to 7:59am	2,564	14.2	30 to 34 minutes to Work	1,097	6.0
Left for Work 8am to 8:29am	1,908	10.5	35 to 39 minutes to Work	89	0.5
Left for Work 8:30am to 8:59am	733	4.0	40 to 44 minutes to Work	14	0.1
Left for Work 9am to 9:59am	1,323	7.3	45 to 59 minutes to Work	310	1.7
Left for Work 10am to 10:59am	1,066	5.9	60 to 89 minutes to Work	160	0.9
Left for Work 11am to 11:59am	366	2.0	More than 90 minutes to Work	160	0.9

Above the service area percentage

Below the service area percentage

Equal to the service area percentage

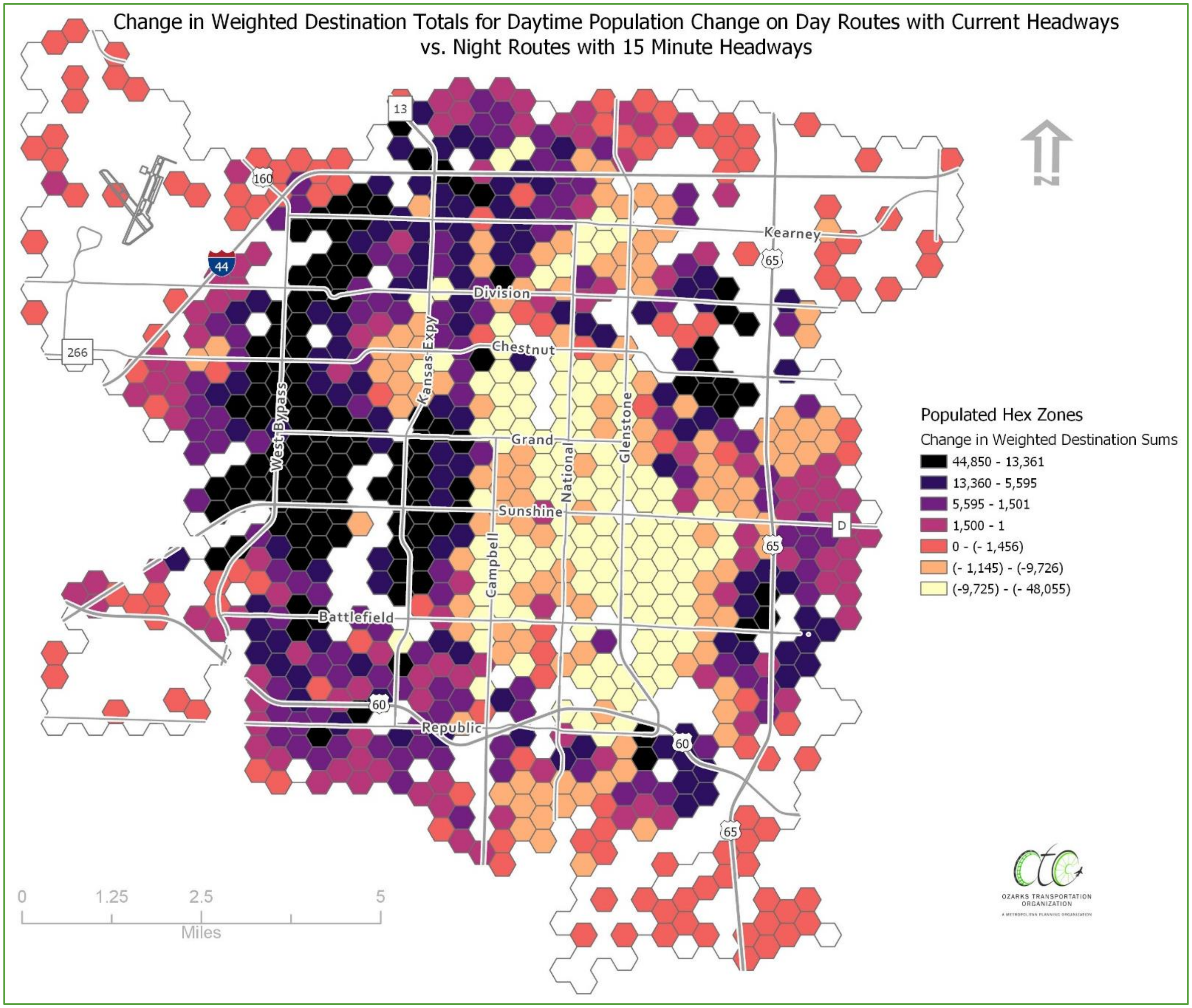

Figure 17: Change in Weighted Destination Sums for Weekday Daytime Routes vs. Night Routes with 15-Minute Headways

Table 4: Estimated 2018 Population Characteristics for Areas with a Change in Weighted Destination Sums Greater than or Equal to 14,690 for Night Routes with 15-Minute Headways

2018 OTO Estimates	Number	%	2018 OTO Estimates	Number	%
Total Pop 2018	22,761	11.2	Left for Work 12pm to 3:59pm	934	9.9
Total Labor Force 2018	9,478	41.6	Left for Work 4pm to 11:59pm	850	8.9
Labor Force Age 29 or Younger	3,504	37.0	Left for Work 12am to 4:59am	243	2.6
Labor Force Age 30 to 54	3,911	41.2	Agriculture, Forestry, Mining Labor Force	35	0.3
Labor Force 55 to 69	2,063	21.8	Construction Labor Force	399	4.2
Pop living in less than $25,000 Income Households	8,149	35.8	Manufacturing Labor Force	907	9.5
Pop living in $25,000 to $49,999 Income Households	7,991	35.1	Wholesale Trade Labor Force	321	3.4
Pop living in $50,000 to $74,999 Income Households	5,471	24.0	Retail Trade Labor Force	1,231	13.0
Pop living in $75,000 and greater Income Households	1,153	5.1	Transportation & Warehousing Labor Force	369	3.9
Drove Alone to Work	7,849	82.8	Information Labor Force	256	2.7
Carpooled to Work	1,123	11.8	Finance & Insurance Labor Force	79	0.8
Public Transit to Work	63	0.7	Real Estate, Rental & Leasing Labor Force	79	0.8
Taxi to Work	11	0.1	Professional, Science, & Technology Labor Force	586	6.2
Motorcycle to Work	1	0.0	Management of Companies Labor Force	9	0.1
Bicycle to Work	63	0.7	Administrative Support & Waste Services Labor Force	433	4.5
Walk to Work	55	0.6	Education & Social Services Labor Force	679	7.2
Other Means to Work	37	0.4	Healthcare Labor Force	1,779	18.7
Worked at Home	257	2.7	Art & Entertainment Labor Force	161	1.7
Pop Living in 0 Vehicle Households	1,260	5.5	Accommodation & Food Service Labor Force	1,061	11.2
Pop Living in 1 Vehicle Households	10,892	47.9	Other Services Labor Force	567	6.0
Pop Living in 2 Vehicle Households	7,779	34.2	Public Administration Labor Force	463	4.9
Pop Living in 3 plus Vehicle Households	2,326	10.2	Less than 5 minutes to Work	382	4.0
Left for Work 5am to 5:29am	300	3.2	5 to 9 minutes to Work	1,010	10.7
Left for Work 5:30am to 5:59am	704	7.4	10 to 14 minutes to Work	1,985	21.0
Left for Work 6am to 6:29am	498	5.3	15 to 19 minutes to Work	2,437	25.7
Left for Work 6:30am to 6:59am	742	7.8	20 to 24 minutes to Work	1,910	20.1
Left for Work 7am to 7:29am	1,246	13.1	25 to 29 minutes to Work	438	4.6
Left for Work 7:30am to 7:59am	1,379	14.5	30 to 34 minutes to Work	714	7.5
Left for Work 8am to 8:29am	1,125	11.9	35 to 39 minutes to Work	78	0.8
Left for Work 8:30am to 8:59am	371	3.9	40 to 44 minutes to Work	120	1.2
Left for Work 9am to 9:59am	454	4.8	45 to 59 minutes to Work	200	2.1
Left for Work 10am to 10:59am	275	2.9	60 to 89 minutes to Work	90	0.9
Left for Work 11am to 11:59am	317	3.3	More than 90 minutes to Work	90	0.9

Above the service area percentage

Below the service area percentage

Equal to the service area percentage

Table 5: Estimated 2018 Population Characteristics for Areas with a Change in Weighted Destination Sums Less than or Equal to -11,850 for Night Routes with 15-Minute Headways

2018 OTO Estimates	Number	%	2018 OTO Estimates	Number	%
Total Pop 2018	34,708	17.0	Left for Work 12pm to 3:59pm	2,108	13.0
Total Labor Force 2018	16,149	46.5	Left for Work 4pm to 11:59pm	2,315	14.3
Labor Force Age 29 or Younger	8,134	50.4	Left for Work 12am to 4:59am	473	2.9
Labor Force Age 30 to 54	5,167	32.0	Agriculture, Forestry, Mining Labor Force	43	0.2
Labor Force 55 to 69	2,848	17.6	Construction Labor Force	690	4.3
Pop living in less than $25,000 Income Households	15,392	44.3	Manufacturing Labor Force	772	4.8
Pop living in $25,000 to $49,999 Income Households	9,111	26.2	Wholesale Trade Labor Force	246	1.5
Pop living in $50,000 to $74,999 Income Households	7,347	21.2	Retail Trade Labor Force	2,605	16.1
Pop living in $75,000 and greater Income Households	2,885	8.3	Transportation & Warehousing Labor Force	599	3.7
Drove Alone to Work	11,922	73.8	Information Labor Force	387	2.4
Carpooled to Work	1,319	8.2	Finance & Insurance Labor Force	317	1.9
Public Transit to Work	270	1.7	Real Estate, Rental & Leasing Labor Force	317	1.9
Taxi to Work	38	0.2	Professional, Science, & Technology Labor Force	1,128	7.0
Motorcycle to Work	78	0.5	Management of Companies Labor Force	26	0.1
Bicycle to Work	199	1.2	Administrative Support & Waste Services Labor Force	584	3.6
Walk to Work	1,496	9.3	Education & Social Services Labor Force	2,229	13.8
Other Means to Work	130	0.8	Healthcare Labor Force	2,298	14.2
Worked at Home	692	4.3	Art & Entertainment Labor Force	488	3.0
Pop Living in 0 Vehicle Households	4,123	11.9	Accommodation & Food Service Labor Force	2,122	13.1
Pop Living in 1 Vehicle Households	16,368	47.2	Other Services Labor Force	910	5.6
Pop Living in 2 Vehicle Households	10,128	29.2	Public Administration Labor Force	313	1.9
Pop Living in 3 plus Vehicle Households	4,083	11.7	Less than 5 minutes to Work	972	6.0
Left for Work 5am to 5:29am	261	1.6	5 to 9 minutes to Work	3,031	18.7
Left for Work 5:30am to 5:59am	375	2.3	10 to 14 minutes to Work	3,790	23.4
Left for Work 6am to 6:29am	773	4.8	15 to 19 minutes to Work	4,237	26.2
Left for Work 6:30am to 6:59am	1,067	6.6	20 to 24 minutes to Work	2,054	12.7
Left for Work 7am to 7:29am	1,610	9.9	25 to 29 minutes to Work	424	2.6
Left for Work 7:30am to 7:59am	2,415	15.0	30 to 34 minutes to Work	945	5.9
Left for Work 8am to 8:29am	1,465	9.0	35 to 39 minutes to Work	42	0.2
Left for Work 8:30am to 8:59am	751	4.7	40 to 44 minutes to Work	37	0.2
Left for Work 9am to 9:59am	1,274	7.9	45 to 59 minutes to Work	159	1.0
Left for Work 10am to 10:59am	950	5.9	60 to 89 minutes to Work	150	1.0
Left for Work 11am to 11:59am	310	1.9	More than 90 minutes to Work	150	1.0

Above the service area percentage

Below the service area percentage

Equal to the service area percentage

CONCLUSIONS

This analysis takes advantage of GTFS tables and transit analysis tools developed by Esri to evaluate transit accessibility in the CU Transit Services area. A multimodal network of local streets, greenway trails, bus routes and stop times enable the calculation of travel time for a combination of walking and bus service to measure the accessibility to activities using transit.

Using the origin/destination points and Create Accessibility Matrix transit analysis tool, areas of high and low transit accessibility to the weighted destinations were identified for current weekday daytime routes, weekday night routes with 20-minute headway, and weekday night routes with 15-minute headways. The cumulative accessibility measure using daytime population change as weights for each alternative was used to explore the efficacy of increasing frequency on night routes compared to existing headways on weekday daytime routes. Characteristics of populations in areas that were affected by changes in accessibility were summarized to measure the impact of alternative routes and schedules.

Weekday Daytime Routes vs. Night Routes with 20-Minute Headways - The average hexagon percentage of destination weights reached for 90% of departure times remained virtually the same using these two routing alternatives from 18.9% to 19% respectively. The average percent change however, was 8.9% indicating modest area wide improvement in accessibility in the service area.

The cutoff for the top 12% of hexagons was a change of 5,000 or more in the sum of destination weights. Total population in these areas is estimated to be 29,824. Percentages for driving alone to work, household incomes $49,999 or less, employment in construction, manufacturing, and retail, accommodation & food service and people living in zero and one vehicle households were greater than the area wide average.

The cutoff for the bottom 12% of hexagons was a change of -3,600 or less in the sum of weighted destinations. Many of these locations were in areas in center city that already had high transit accessibility due to proximity to the transit center. Total population in these areas is estimated to be 37,513. Percentages for walking to work, household incomes less than $25,000, workforce age 29 and younger or less, employment in construction, retail, education, accommodation & food service and people living in zero and one vehicle households were greater than the area wide average. Estimates for public transit to work were also higher.

Weekday Daytime Routes vs. Night Routes with 15-Minute Headways- The average hexagon percentage for destination weights reached for 90% of departure times rose to 29.6% for the night route alternative with 15-minute headways compared to current weekday daytime routes. The average percent change was 60% indicating dramatic improvement in accessibility in the service area.

The cutoff for the top 12% of hexagons was a change of 14,690 or more in the sum of destination weights reached during the time window. Total population in these areas is estimated to be 22,761. Percentages for labor force ages 29 and younger, population living in households with incomes of $49,999 or less, driving alone to work and carpooling, one vehicle households, and employment in manufacturing, healthcare, accommodation & food services are all higher than the service area percentages.

The cutoff for the bottom 12% of hexagons was a change of -11,850 or less in the sum of destination weights reached during the time window. Total population in these areas is estimated to be 34,708. Percentages for total labor force, labor force age 29 or younger, people living in households with income less than $25,000, public transit to work, walk to work, population living in zero and one vehicle households, employment in retail, education, and accommodation and food service, and 14 minutes or less to work are all higher than the service area percentages.

Transit accessibility to activity centers in both night route alternatives improves in areas with below average accessibility and low-income areas for existing weekday daytime routes and schedules. In these areas there are more than the total area percentage of people driving alone to work and carpooling and a lower percentage of people using alternative modes. This is likely a function of poor access to employment and activity centers in these areas. Higher frequencies of service on evening routes improves accessibility in these areas and would provide a benefit that was not previously available.

Conversely, locations with worsening transit accessibility to activity centers are proximate to downtown and along the Glenstone corridor from Sunshine to Battlefield. In these areas there are a higher percentage of people in zero and one vehicle households, below $25,000 income households, and a significantly larger percentage of the labor force age 29 and younger. People in these areas also use alternate means of transportation to work and enjoy shorter commute times. This is likely a function of proximity to college campuses and high transit accessibility to activity centers on existing transit routes and schedules.

The deciding factor in pursuing route alternatives would be the effect on ridership on the bus system. The large population of college-aged people living in and around downtown are likely not using CU Transit Services but enjoy the greatest benefit in terms of accessibility to area activities. The population living in areas with lower accessibility would realize greater benefits and may increase ridership.

Of the two alternatives, the 20-minute headways on night routes appears to be the best alternative. While each improve efficiency and travel times for areas that could benefit from connectedness to opportunities and activity in the CU Transit Service area. The 20-minute headways would accomplish this with the least shock to the system in terms of cost and benefits and would be worth further investigation and refinement according to the methodology used in this analysis.

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