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GEOG 4303

Identifying Public Transportation Disadvantaged Census Tracts in Denver County

Research Question

Places and the things that occupy those places are defined by people's ability to access that place. Things like businesses, parks, and much more will be unsuccessful if people cannot access them. Likewise, a person's life will be worse off if they are unable to access things like health services, educational facilities, places to work, or even just a bar to enjoy their Friday night. Thus, getting around is essential to both defining places and people's lives.

Public transportation affords the opportunity to transport large groups of people around locations. When available, public transit yields economic, environmental, and social boons. Murray, Davis, Stimson and Ferreira state "Transportation systems form the basis by which economic development can occur and the means by which society interacts," (Murray, 1998, p. 320). In a review of forty studies related to public funded transportation projects (not limited to just public transit), Bhatta and Drennan concluded that "Public sector investments in transportation infrastructure result in long-term economic benefits on the production or supply side, such as increased output, increased productivity, reduced costs of production, or increased income," (Bhatta, 2003, p. 295). Transit generally is the backbone of all development in any area. Readily available public transportation versus just something like a road has the effect of being more accessible to all citizens, since it does not necessitate something like a car. In this sense public transportation can be an equalizing factor for people without cars, defining their range of movement and thus opportunity. In that sense, public transportation is of great importance to economic justice and creating a more even playing field for all involved. Environmentally, public transportation can reduce emissions and fuel consumption. Newman and Kenworthy observed that cities with low urban density had higher fuel use compared to high density cities. They say "but without direction in land use and commitment of transportation resources to non-automobile modes, these policies will not be sufficient" referring to policies regarding automobile vehicle efficiency, and gasoline price intended to reduce gasoline use (Newman, 1989, p. 35). That being said, it becomes clear that an understanding of where public transportation does and doesn't exist is an important endeavor for citizens, businesses, and governments alike to undertake to ensure the health and development of their communities.

Denver County features a diverse set of 178 census tracts. As the seat of Colorado's capital city Denver, Denver County stands as an important county in the region. As Colorado's biggest metro area, Denver has more public transit than other counties and the health of public transit in this city is important for the state as a whole. This leads to the research question:

Where does public transit exist and lack in Denver County and what areas of Denver County have the least access to transit?

Public transportation in Denver County is currently dominated by the Regional Transportation District aka RTD, a regional transportation agency. RTD provides transportation

in eight different counties in Colorado including Denver. It is headed by a 15-person Board of Directors that is publicly elected by constituents (“Who We Are.”). RTD was created in 1969 by the state legislature, with light rail services beginning in 1994 (“Who We Are.”). In Denver County, it operates both bus routes and light rail, with light rail being unique to mainly Denver (in Colorado). Light rail has twelve lines that service 78 stations (“Who We Are.”). Other transportation services exist within Denver County such as the Bustang run by the Colorado Department of Transportation offering intercounty travel, but these other transportation sources are eclipsed by RTD’s dominance. A preliminary analysis of transit stops derived from the National Transit Map Stops data set put together by the Department of Transportation shows that there are about 2,634 transit stops in Denver County. Denver County’s unique position as a place within Colorado as a place with both light rail and bus services makes it a particularly interesting and suitable study area for the above research question.

Objectives

The main objective of this project is to evaluate and identify census tracts within Denver County that are public transportation disadvantaged. To determine this disadvantage, a ranking system based on a list of 21 indicators grouped into 6 categories will be used (More Details in Methodology). A majority of the list was heavily inspired by the Department of Transportation’s Justice40 Initiative criteria for determining disadvantaged communities (“Transportation”). One additional factor was added to the DOT’s original 22 to make it more public transit specific. This factor was stops per 1000 people. Two indicators from the DOT’s original list were removed, walkability and transportation burden. Information from the CDC on social vulnerability was also used in the early stages of deciding on indicators (Flanagan). One other objective is to create a visual representation of where transit stops exist in Denver County using hot spot analysis.

Deliverables

The main deliverable for this project is an [ArcGIS Online map](#) identifying the disadvantaged tracts. This map is interactive and allows user to click on each census tract, allowing them to see the tract’s score breakdown for each of the six categories, overall score, and tract name. In addition to this map, eleven other maps were produced. These maps showcase in JPG format total disadvantage score across all categories, disadvantaged or not for each category, and a JPG version of overall disadvantage showcase. There are also three JPG maps (as part of the eleven) that show hotspot analysis on transit stops in Denver County using different aggregation methods. One uses fishnets, hexagons, and finally census tracts to aggregate stops. Another set of deliverables is a series of CSV files. One contains the 21 indicators for each census tract, one features disadvantage scores and percentile scores for each category of overall disadvantaged tracts, another features all indicator information and percentile information on each indicator for overall disadvantaged tracts, and finally one contains all tracts and their score breakdowns for disadvantage. The final main deliverable is a Jupyter Notebook containing Python code that conducts the disadvantage analysis. By building code within a Jupyter Notebook, markdown that describes the methods being used in the code was able to be put in. All these deliverables plus the raw data can be found at this [GitHub repo](#). This final report and a final presentation were also created.

Data Sources

TIGER/Line data from the U.S. Census was used to define the census tracts boundaries and code. Transit stops were acquired from the Bureau of Transportation Statistics from the National Transit Map Stops layer. Data sources for demographic information regarding the 21 indicators came from a variety of governmental agencies. See Figure 1 for each indicator's source. Links and more detailed information about all data sources are available at the bottom of this report.

Methodology

The 21 indicators are displayed on the left in the table below, while their respective categories (of the 6) are to the right. Additionally, their data source is listed on the right.

Indicator	Description	Category	Source
Stops per 1000 People	Number of Transit Stops Per 1000 People For the Census Tract	Transportation Access	Derived from National Transit Map Stops
> 30 Min Commute	Percentage of Total Pop. With a Commute Greater than or Equal to 30 Minutes		2016-2020 American Community Survey
No Vehicle Access	Percentage of occupied housing units with no vehicles available		Community Resilience Indicators (FEMA)
Population 65 and Older	Percentage of the population 65 years and older	Health	Community Resilience Indicators (FEMA)
Uninsured	Percentage of the population without health insurance coverage		Community Resilience Indicators (FEMA)
Disability	Percentage of the population with a disability		Community Resilience Indicators (FEMA)
Homes Built Before 1960	% Of Homes Built Before 1960 (Lead Paint Indicator)	Environmental	EJ Indexes (EPA)
Diesel	EJ Index for Diesel particulate matter level in air		EJ Indexes (EPA)
Cancer	EJ Index for Air toxics cancer risk		EJ Indexes (EPA)
Traffic Proximity	EJ Index for Traffic proximity and volume		EJ Indexes (EPA)
PM25	EJ Index for Particulate Matter Diameter 2.5 micrometers and smaller in air. (Fine Particles).		EJ Indexes (EPA)
Ozone	EJ Index For Ozone in Air		EJ Indexes (EPA)
Less HS Education	Percentage of population over age 25 without a high school diploma (including GED)	Economic	Community Resilience Indicators (FEMA)
Renters	Percentage of Occupied Housing Units not by Property Owner		Community Resilience Indicators (FEMA)
Unemployment	Percentage of the labor force unemployed		Community Resilience Indicators (FEMA)
GINI Index	GINI Index of income inequality (income distribution across a population)		Community Resilience Indicators (FEMA)
Low Income	% Low Income		EJ Indexes (EPA)
Poverty	Percentage of Persons Below 150% Poverty Estimate (Federal Poverty Level)		CDC/ATSDR Social Vulnerability Index
Housing Costs	Percentage of housing cost burdened occupied housing units with annual income less than \$75,000 (30%+ of income spent on housing costs)	Resilience	CDC/ATSDR Social Vulnerability Index
Climate Hazards	Expected annual loss of life, building value and agricultural value from 18 climate hazards		National Risk Index Colorado (FEMA)
Linguistic Isolation	Percent of households in linguistic isolation (Limited English speaking households)	Equity	Community Resilience Indicators (FEMA)

Figure 1: This figure displays the 21 indicators used in this project, their description, the category they belong to and their data source.

The ranking system of the 21 indicators operates by calculating percentiles for each indicator for each census tract in relation to the other census tracts in the area of interest. All census tracts information will be placed together. Percentiles are calculated using the equation below:

$$\frac{\# \text{ of Values below TractValue}}{n} = \text{TractPercentile}$$

Ultimately, this means that for each of the 21 indicators, each census tract's value for that indicator will be compared to all other census tracts. The number of values from the other census tracts that fall below the current tract's score will be calculated and that number will be divided by n which is the total number of tracts. This yields your percentile score. This will be done for every indicator except stops per 1000 people for every tract. This formula works for most indicators because they are negative indicators, meaning that the higher the score the worse it is. This project is interested in looking at places of disadvantage, so we are looking for higher scores. One indicator, however, Stops Per 1000 People, is a positive indicator meaning that the higher the score the better. To calculate this indicators percentile, the equation is flipped since

lower scores need to be the higher percentiles. Thus, Stops Per 1000 people utilizes this equation:

$$\frac{\# \text{ of Values Above } TractValue}{n} = TractPercentile$$

However, all other indicators besides Stops Per 1000 people still use the first equation.

Once scores for all the indicators are calculated, scores will be averaged for each category. For example, the health category consists of the indicators Population 65 and Older, Uninsured and Disability. So, these three indicators percentile score will be averaged together. Then if the averages score is 0.5 or higher the category will be assigned a score of 1 to represent disadvantage in that category, 0 otherwise. For the resilience category only, it is considered disadvantaged if the average score is 0.75 or higher. Once the score for each category is calculated, a census tract will be ranked overall transportation disadvantaged if the cumulative score amongst categories is a 4 or higher. These scores will be added to the attribute tables for each census tract. It is worth it to note that while transportation access is its own category, the disadvantage in this category alone does not represent overall transportation disadvantage. This project aims to take a more wholistic view of factors that could hamper transportation equity and thus the other categories exist to try to consider things like economic and health factors that could affect a place's transportation.

To do this ranking, a Python script within a Jupyter Notebook was developed that reads in an excel spreadsheet containing all census tracts and the indicators for each tract. This data is stored in custom census tract objects that contain member variables of all the indicators, and all the census tracts from the spreadsheet are stored in a list. Using NumPy arrays, percentiles are calculated, categories are scored, and disadvantage is identified. The notebook which contains more detailed documentation is available [here](#).

The cluster analysis of where stops are in Denver County was done using the Optimized Hot Spot Analysis tool in ArcGIS Pro. This tool determines if there is any statistically significant clustering of points in the input shape file. The Denver Transit Stops layer was inputted into this tool. Three different 'Incident Data Aggregation Methods' were used including counting incidents within fishnets, within a hexagon grid, and within polygons defined by the Denver County Census Tracts. This produced three different feature layers that were mapped later.

Phase/Objective 1: Data Aggregation & Acquisition

This phase produced a geodatabase containing all relevant GIS data (stops, census tracts). This geodatabase also included the clipped and projected versions of bigger data sets. For example, it included the stops only in Denver County obtained by clipping the National Transit Stops layer with Denver County. An excel spreadsheet aggregating the required demographic information for each census tract was produced.

- Task 1: Find data from agencies. **Duration:** 4 hours
- Task 2: Aggregate data into a usable format. This entails putting the demographic data related to the indicators into an excel spreadsheet that can easily be read by the python

ranking script. One must construct their excel spreadsheet where the first column is the NAMELSAD of the census tract, and then the following columns are the indicators in the order from top to bottom depicted in Figure 1. **Duration:** 5 hours

- Task 3: Project National Transit Map Stops layer into same coordinate system as 2022 TIGER/Line Census Tract Boundaries. **Duration:** 2 hours
- Task 4: Use a select by attributes query within ArcGIS Pro to select census tracts from the 2022 TIGER/Line Census Tract whose COUNTYFP = 031. This is selecting only census tracts within Denver County. Export this selection to a new layer. **Duration:** 15 minutes
- Task 5: Use the clip tool in ArcGIS Pro to clip the projected National Transit Map Stops layer to the Denver County Census Tracts. Input Feature: Transit Stops, Clip Feature: Denver County Census Tracts. **Duration:** 15 minutes

Resources Needed: Internet, Free Data (Mostly from the government), Microsoft Excel and Word (For Aggregating and Keeping Track of Data Sources), ArcGIS Pro (For Clipping and Coordinate Changing), Hard drive and Cloud Storage for storing data, Computer (For all of the above), Professor Kelly or Phil White if any challenges crop up.

Phase/Objective 2: Preliminary Analysis

The deliverables for this objective were maps depicting hot/cold spots for stops.

- Task 1: Determine stop density (stops per 1000 people) for each census tract within Arc. This is done by using a Spatial Join in ArcGIS Pro where the target feature is the Denver County Census Tracts, and the Join Feature is the Clipped Transit Stops. This will count the number of stops per tract. Then use total population for each tract to get stops per 1000 people through division. **Duration:** 3 hours
- Task 2: Use the Optimized Hot Spot Analysis tool in ArcGIS Pro to determine statistically significant hot and cold spots of transit stops in Denver County. The input feature is Transit Stops Clipped. Do three different runs of this tool using the incident data aggregation methods of fishnets, hexagons, and census tract polygons **Duration:** 2 hours
- Task 3: Map hot/cold spots for transit stops based on previous result. This will be done in ArcGIS Pro and should be a high-quality JPG map as it is one, for use as a deliverable. **Duration:** 2 hours

Resources Needed: Internet (To Figure out Tools), Aggregated Data, Microsoft Excel and Word (Data Access), ArcGIS Pro (For Clipping, Counting, and Cluster Analysis) Hard drive and Cloud Storage containing data, Computer (For all of the above), Professor Kelly if challenges regarding cluster analysis pops up.

Phase/Objective 3: Determine Disadvantaged Tracts

The deliverables for this objective include a python script to calculate the disadvantaged level for each census tract in Denver County, an Arc GIS Online map that is interactive and allows users

to see the category scores for each tract. Another deliverable is spreadsheets that feature detailed information about disadvantaged tracts.

- Task 1: Write and execute a Python script within a Jupyter Notebook that does the analysis on the 21 indicators and 6 categories to determine if a census tract is transportation disadvantaged. This is done in Python since it is a series of calculations rather than anything that really necessitates ArcGIS Pro. Requires loading in a moderate amount of data and doing analysis. The script reads in a CSV file, performs calculations, and exports three different CSV reports. **Duration:** 10 hours
- Task 2: Perform a Join Field between tract shape file and tract ranking calculations CSV from above. Join Field will be NAMELSAD, and transfer field will be disadvantage scores. Create a new Layer that is Census Tracts with Rankings. This new layer will have the disadvantage rankings added to the actual geographic locations of each census tract. **Duration:** 1 hour
- Task 3: Map the census tracts in Denver County, clearly displaying those identified as transportation disadvantaged. Create an Arc GIS Online map that will contain a feature layer showing the breakdown of category scores for each tract. Users will be able to interact with this. **Duration:** 5 hours
- Task 4: Make JPG Maps breaking down disadvantage scores for each category, total score, and overall disadvantage. Done in ArcGIS Pro **Duration:** 3 hours

Resources Needed: Internet (For any Python Googling Needed), Aggregated Data, Jupyter Notebook, ArcGIS Pro (For Creating the Maps), Microsoft Excel and Word (Access Data and make Table), Hard drive and cloud storage containing data, Computer.

Results

The disadvantage analysis of census tracts in Denver County yielded 70 census tracts that were overall public transportation disadvantaged. This is around 39% of all census tracts in Denver County. There were only 4 tracts with a disadvantage score of 6 meaning that they were disadvantaged in every category. Conversely there were 15 tracts that had no disadvantage in any category. Rounding out overall disadvantaged tracts, there were 29 tracts that scored a 4 and 37 tracts that scored a 5. Interestingly, the tract numbers for each individual category that were disadvantaged were much higher than overall with most hovering around 90 tracts disadvantaged in that category. The exception to this was the resilience category but that was to be expected since its threshold for disadvantage is a percentile of 0.75 versus 0.5. A map of the overall disadvantage and total disadvantage scores are below in Figures 2 and 3.

Denver County Overall Disadvantage

Description: This is a map depicting overall disadvantage of the census tracts in Denver County for 2020 data. This ranking is based off of a composite of six categories, where a score of 1 in each of those categories represents disadvantage. To be overall disadvantaged, a tract must have a score of 4 or above.

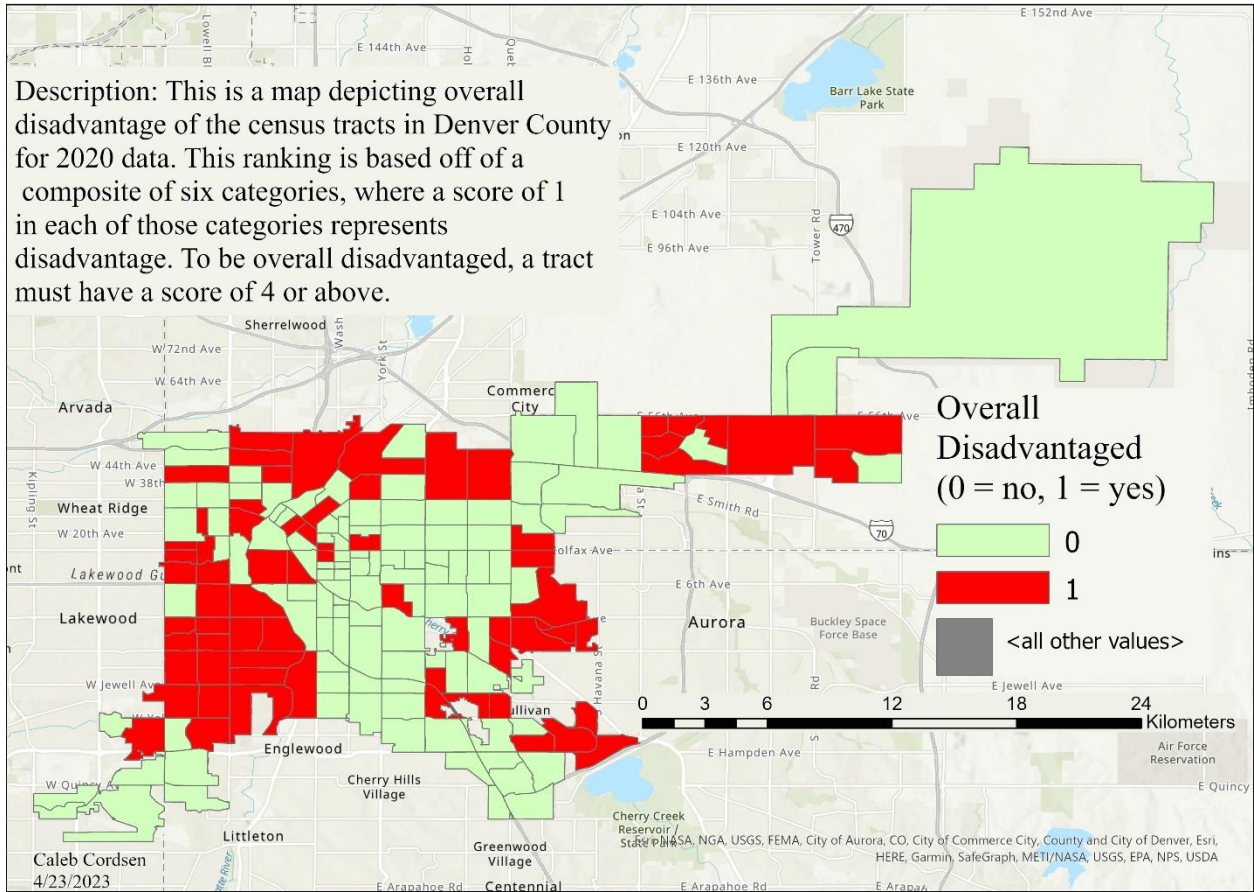


Figure 2: This figure displays a map of Denver County depicting overall disadvantage in census tracts. Disadvantaged tracts are depicted in red while non-disadvantaged tracts are depicted in a light green color.

Denver County Disadvantage Total Score

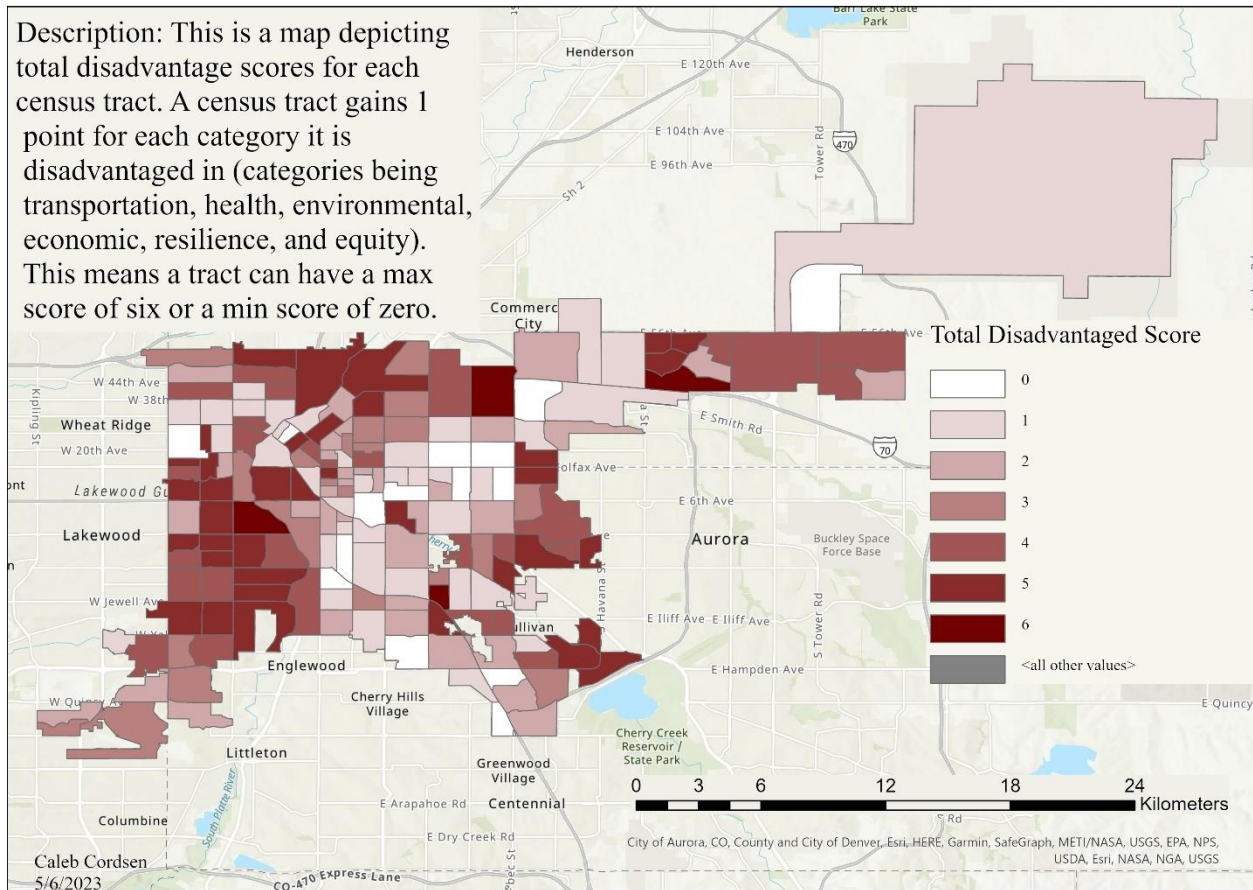


Figure 3: This figure displays a map of Denver County showing total disadvantage score in census tracts. Total score operates on a scale of 0 to 6 based on individual category scores.

In Denver County, there is this notion of the “inverted L” (“City”, p. 10). The inverted L is an inverted L shape across Denver County that represents Denver’s vulnerable neighborhoods and census tracts (“City”, p. 10). This boundary is roughly aligned with I-70 and I-25 and neighborhoods along this L shape are often more diverse and lower income. Interestingly, in the results from Figure 2 we can see a sort of semblance of the inverted L starting at the left-hand side of the county working up and then heading right. This pattern can be seen even more clearly in the maps for individual category disadvantage in the economic (Appendix A) and environmental (Appendix B) categories. The pattern still can be loosely seen in the equity map (Appendix C) but is not so clear in health (Appendix D), resilience (Appendix E) or transportation (Appendix F). This backs up the notion of the inverted L as has been observed of being a place of disadvantage in Denver County and helps to verify the results of this project by showcasing an already somewhat known phenomenon. Other areas of disadvantage that seem common to many categories and overall disadvantage is the Southeast of Denver and Northeast below DIA. Both these areas have clusters of census tracts that are overall disadvantaged.

Denver County Transit Stops Fishnet Hotspots

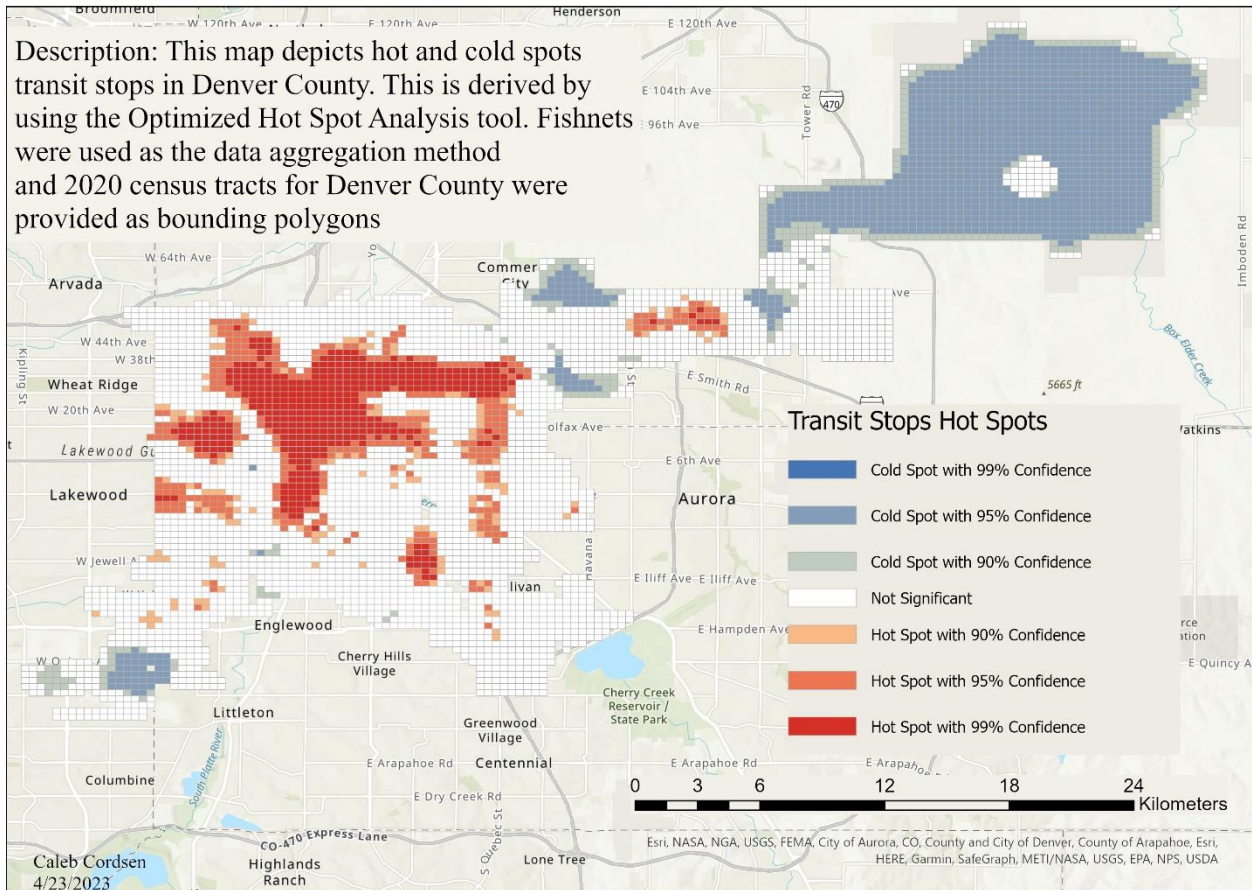


Figure 4: This figure displays a map of Denver County showing a hot spot analysis of transit stops. This figure shows a hot spot analysis done using fishnets as the data aggregation method.

Denver County Transit Stops Hexagon Hotspots

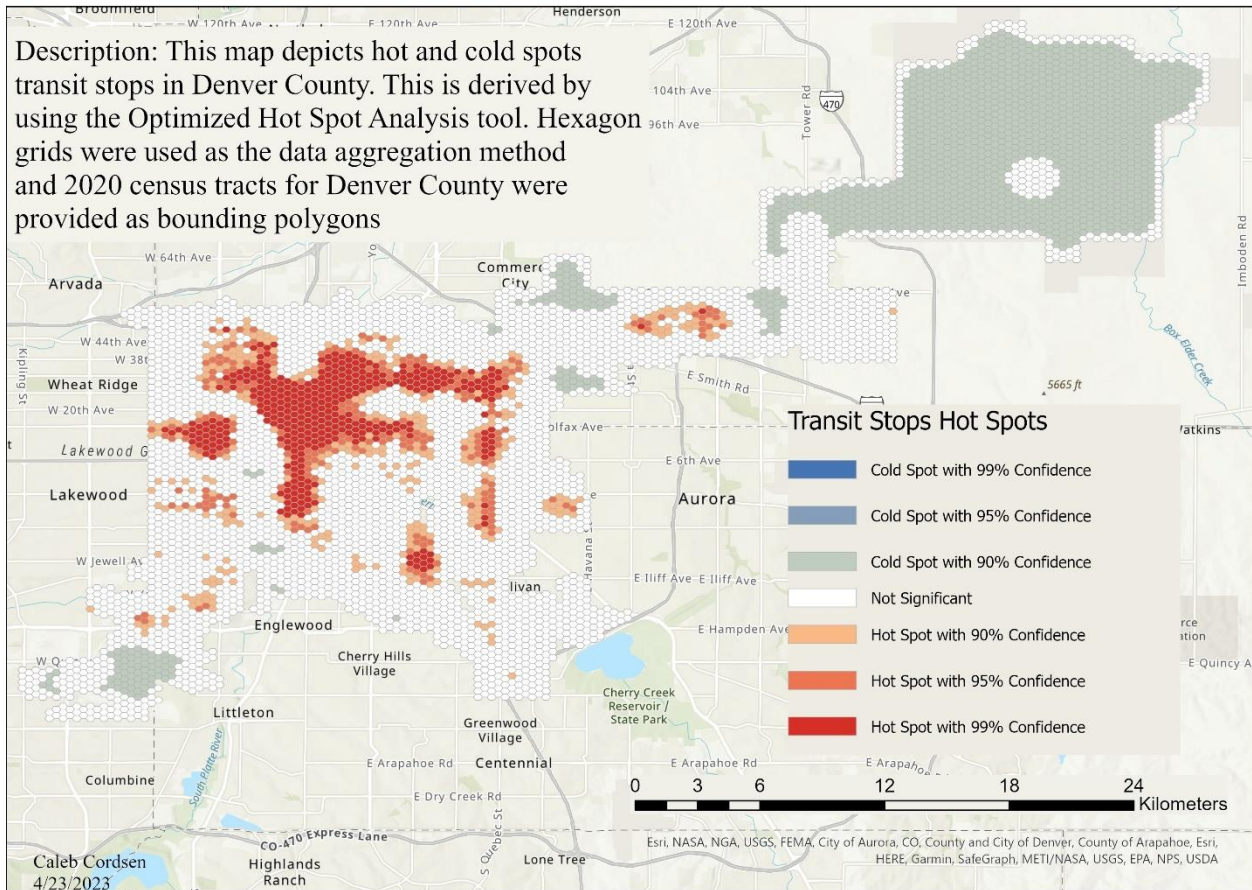


Figure 5: This figure displays a map of Denver County showing a hot spot analysis of transit stops. This figure shows a hot spot analysis done using hexagons as the data aggregation method.

Denver County Transit Stops Polygon Hotspots

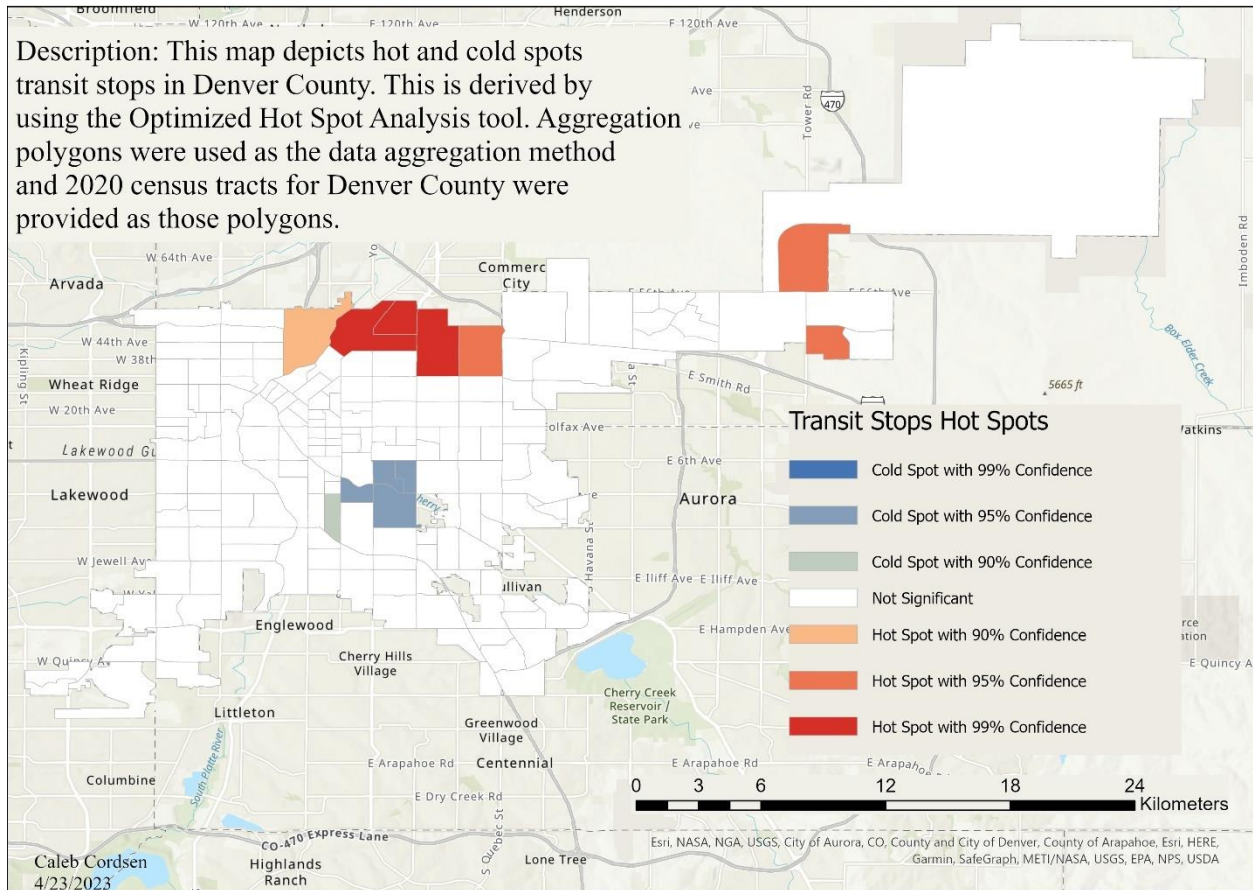


Figure 6: This figure displays a map of Denver County showing a hot spot analysis of transit stops. This figure shows a hot spot analysis done using polygons as the data aggregation method where the polygons were 2022 census tracts.

Figures 4, 5, and 6 display three different methods of hot spot analysis on transit stops in Denver County. From these maps, it can be seen that transit stops themselves are fairly well distributed in Denver County. None of the three maps identify any cold spots with 99% confidence. Both Figure 4 and Figure 5 identify similar hot and cold spots. They identify the center of Denver County as a large zone for hot spots with some other hotspots distributed throughout, like in the Northeast. They both identify DIA in the Northeast as a cold spot as well as places like the Southwest as a cold spot. Figure 4 and Figure 5 overall depict very similar results but with Figure 5 showing slightly less confidence. Figure 6 on the other hand displays very different results, only identifying a few census tracts in the North of the county as hot spots and the only cold spots being in the middle of the county. One potential explanation for these differences is their different aggregation methods. Figure 4 uses fishnets and Figure 5 uses hexagons which while different areas, have similar areas of coverage and data that get put into each shape. Figure 6 on the other hand uses census tracts to aggregate data points, and these census tracts are much larger than each fishnet or hexagon. Since Figure 6 has many more data points being aggregated into each tract, it is much easier to bypass the minutiae of stop

distribution, hence why most of the map is not significant in terms of results. Figure 4 and Figure 5 have smaller areas of analysis and thus are able to capture better the actual stop distribution phenomena. Figure 4 and 5 should be looked at as more reliable results for stop hot spots than Figure 6.

Taken together, the hot spot and disadvantage analysis helps us to identify the inverted L shape as a place where transportation could be further expanded upon.

Timeline

Included below is the project's Gantt chart schedule displaying tasks and deadlines for said tasks. It is split into 6 milestones, mainly based on assignment submissions, and can be seen below:

TASK	Hours	Dependencies	PROGRESS	START	END
Milestone 1: Vision Statement and Brainstorming Project					
Brainstorm Project Ideas	1 hour	None	100%	1/17/23	1/20/23
Pick One Idea	30 minutes	FTS on Brainstorm Project Ideas	100%	1/20/23	1/22/23
Do Brief Overview of Feasibility	1 hour	FTS on Pick One Idea	100%	1/22/23	1/26/23
Write Vision Statement	1 hour	FTS on Overview of Feasibility	100%	1/26/23	1/26/23
Milestone 2: Statement of Intent					
Literature Review	11 hours	STS on Brief Overview of Feasibility	100%	1/22/23	4/2/23
Find Data	3 1/6 hours	STS on Brief Overview of Feasibility	100%	1/22/23	3/10/23
Define Ranking Methodology	2 hours	STS with Literature Review	100%	2/14/23	2/19/23
Define Objectives & Deliverables	2 hours	STS with Define Ranking	100%	2/17/23	2/19/23
Prepare for Lightning talk	1 hour	FTF with Define Obj/Deliverables	100%	2/19/23	2/21/23
Write Statement of Intent	2 hours	FTF with Define Obj/Deliverables	100%	2/19/23	2/21/23
Milestone 3: Draft Proposal					
Break Down Sub-Tasks For Each Deliverable	2 hours	FTS on Statement of Intent	100%	2/21/23	2/26/23
Update Gantt Chart	2 hours	FTS on Sub-Task Break Down	100%	2/26/23	3/4/23
Aggregate Data Into Usable and Compact Format	5 hours	FTS on Find Data	100%	3/10/23	3/29/23
Write Draft Proposal	2 hours	FTF with Update Gantt Chart, FTS on Statement of Intent	100%	2/26/23	3/5/23
Milestone 4: Lightning Talk 2					
Create Script To Put All Data in Same Coordinate System	1 hour	FTS on Data Aggregation	100%	3/10/23	3/10/23
Clip Big Data Sets to Area of Interest	1 hour	FTS on Common Coordinate System	100%	3/10/23	3/11/23
Create Script to Count Num of Stops Per Tract + Determine Stop Density	3 hours	FTS on Clip to Area of Interest	100%	3/12/23	3/29/23
Perform some sort of Cluster Analysis On Stops	2 hours	FTS on Clip To Area of Interest	100%	3/12/23	4/22/23
Map Cluster Analysis + Stop Density/Num of Stops	2 hours	FTS on Cluster Analysis and Stop Density Script	100%	3/13/23	4/23/23
Prepare for Lightning Talk 2	1 hour	None (Since its just a recap of what's happened)	100%	3/12/23	3/14/23

Milestone 5: Final Proposal					
Create Script to Calculate Ranking/Disadvantaged Level of Each Tract of Interest	10 hours	FTS on Clip To Area of Interest, FTF On Stop Density Script	100%	3/12/23	4/22/23
Review Project After Analysis (Is there more to be done? Things to be modified?)	3 hours	FTS on All Analysis (Ranking Script, Cluster, Density Script)	100%	4/23/23	4/23/23
Revise Uncertainties	1 hour	STS on Review Project	100%	3/28/23	4/2/23
Finalize References	1 hour	FTS on Literature Review	100%	3/28/23	4/2/23
Write Final Proposal	6 hours	FTF on References, FTF on Uncertainties, FTS on Draft Proposal	100%	3/31/23	4/2/23
Milestone 6: Wrapping Up					
Map Disadvantaged Tracts	2 hours	FTS on Script to Calculate Disadvantaged Tracts	100%	4/22/23	4/24/23
Make Table Graphic About Disadvantaged Tracts	1 hour	FTS on Script to Calculate Disadvantaged Tracts	100%	4/22/23	4/24/23
Make Other Misc. Maps or Graphics	2 hours	FTS on All Analysis (Ranking Script, Cluster, Density Script)	100%	4/24/23	4/24/23
Formalize Interpretation of Results	2 hours	FTS on All Analysis, FTF With Making of Maps + Graphics	100%	4/24/23	4/25/23
Make Project Presentation	4 hours	FTS on All Analysis, FTF With Making of Maps + Graphics, FTF with Results	100%	4/2/23	4/25/23
Practice and Give Presentation	3 hours	FTS on Making of Presentation	100%	4/20/23	4/25/23
Write Final Report	10 1/3 hours	FTS on Final Proposal, FTF on making Graphics, FTF With Results	95%	4/2/23	5/6/23

Figure 7: This figure displays the projects Gantt Chart. The Gantt Chart depicts project tasks, their duration estimate, their dependencies, their completion status, and their start and end dates. This chart shows the actual timeline the project followed.

Dependencies

Dependencies are listed for tasks in Figure 7 above according to a key where FTS = Finish to Start, STS = Start to Start, and FTF = Finish to Finish dependency.

Evaluation Plan

Below is an overview of the evaluation plan for this project. Deadlines are based on the original Gantt chart dates from the onset of the project and may not reflect the updated Gantt chart. Refer to the key for color meanings.

Stage/Milestone	Task	Deadline	Status	Notes	Key
Vision Statement and Brainstorming	Brainstorm Project Ideas	1/20/2023		Fun Brainstorming Things	Good Quality; On Time
	Pick One Idea	1/22/2023		Hard to narrow down to one idea but overall good	Good Quality; Late
	Brief Overview of Feasibility	1/26/2023		Successfully completed with lots of sources	Subpar Quality; On Time
	Write Vision Statement	1/26/2023		Able to write vision statement to a quality I like and received excellent feedback on how to narrow scope to something more	Subpar Quality; Late
Statement of Intent	Literature Review	2/23/2023		Literature Review is done (unless I decide I need more sources based on Final Proposal feedback). I forgot to update this in my Final Proposal but this was finished prior to that.	Late In Progress
	Find Data	2/24/2023		I also forgot to update this in my Final Proposal but it was finished prior to that. I had to throw out collecting the data for access to transportation for low income workers since it was at the block group level rather than census tract. If I had a lot of time left over I may try to aggregate this data at the census tract level and add back in	
	Define Ranking Methodology	2/19/2023		Was able to successfully define my ranking methodology to a quality that I like including aspects that I think are important. Still room to grow potentially later in semester	
	Define Objectives and Deliverables	2/29/2023		Defined the objectives after getting my ranking system and put in a clear set of deliverables. Could make the final product more clear.	
	Prepare for Lightning Talk	2/21/2023		Lightning Talk went well, preparation and power point for it turned out good. Satisfied with first talk	
	Write Statement of Intent	2/21/2023		Completed on time, and with minimal difficulty. Came out well and satisfied with feedback and quality	
Draft Proposal	Break Down Sub-Tasks For Each Deliverable	2/26/2023		I pretty much got all of the sub-tasks on my first pass on my Gantt chart, so nothing really to do here.	
	Update Gantt Chart	3/4/2023			
	Aggregate Data Into Usable and Compact Format	3/7/2023		I had to drop some indicators due to being unable to find data for those indicators, so I would say this was the most disappointing part of my project. I still had the majority of my indicators but since I had to drop some, I am listing this as subpar quality	
	Write Draft Proposal	3/5/2023		Successfully got an alright score and turned in on time	
Lightning Talk 2	Create Script to Put All Data In Same Coordinate System	3/10/2023		This was changed away from a full script and just ran individually from within Arc. There was not enough layers to warrant writing a script for it rather than just doing it manually.	
	Clip Big Data Sets to Area of Interest	3/11/2023			
	Create Script to Count Num of Stops Per Tract + Determine Stop Density	3/12/2023		Similar to the coordinate system script, there was not enough layers to warrant making a script here rather than just using arc	
	Perform Cluster Analysis on Stops	3/13/2023		Successfully performed hot spot analysis and was able to try three different types, fishnets, hexagons and polygons. Somewhat	
	Map Cluster Analysis + Stop Density/Num of Stops	3/14/2023		Successfully made three hotspot maps depicting the three different kinds of analysis done. I am pleased with maps.	
	Prepare for Lightning Talk 2	3/14/2023		Lightning talk went well!	
Final Proposal	Create Script to Calculate Ranking/Disadvantaged Level of Each Tract	3/26/2023		Really pleased with how my script turned out despite the fact that it is late. I ended up making this a jupyter notebook instead of a straight up python script which I hadn't originally planned. However, my jupyter notebook allowed me to annotate the code much cleaner than a straight python file. This makes me happy because it is a much higher quality deliverable for people to look at then before.	
	Review Project After Analysis (What more to do/change?)	3/28/2023		Nothing changed	
Wrapping Up	Revise Uncertainties	3/30/2023		Done Nicely	
	Finalize References	3/30/2023		Done as part of final proposal	
	Write Final Proposal	4/2/2023		Successfully wrote and turned in for solid grade. Do need a bit more text for final report	
	Map Disadvantaged Tracts	4/8/2023		This turned out well. I was able to make both an Arc GIS online map and some jpg map. Generally pleased with how these turned out	
	Make Table Graphic about Disadvantaged Tracts	4/10/2023		These ended up being produced by my script with 3 different CSV tables. Pleased with how these turned out and how they were automated through script	
	Make other Misc. Maps or Graphics	4/11/2023		None needed	
	Formalize Interpretation of Results	4/17/2023		Done as part of project presentation	
	Make Project Presentation	4/21/2023			
	Practice and Give Presentation	4/25/2023			
	Write Final Report	5/6/2023			

Figure 8: This figure displays the projects evaluation plan. It lists original deadlines for tasks and then a key on their status reflecting late, on time and quality factors. It also includes notes about each task.

Risks Encountered

Throughout the project some risks were encountered and changed the scope of the project from its original inception accordingly. Originally, there were supposed to be 24 indicators but three had to be dropped because of difficulties finding data. The indicators were accessibility to transit for low-income workers, walkability, and transportation burden. These three indicators had to be dropped for similar reasons, those being that the data was at the block group level rather than the census tract level. It was not time feasible to try to aggregate it up to the census tract level. To deal with this risk, these indicators were left on the cutting room floor in favor of the 21 other indicators. Due to the nature of having so many indicators to begin with, dropping these indicators was not a huge detriment to the final deliverables of this project.

Uncertainties

There are a number of uncertainties about the final deliverables of this project. The first one arises from the volume of data that had to be aggregated to gain all 21 indicators. Since so much data had to be placed together and this work was done in excel, it's possible at some point in the process a cell got deleted or two cells swapped which could lead to untrue results in the

deliverables. Another uncertainty that has come up was concerning the American Community Survey that some of the indicators relied on. It was taken from the 2016-2020 American Community Survey and used 2020 census tract boundaries to report results. The uncertainty arises in how they did this since from 2016-2019 they would not have had the 2020 census tracts. So, it is unclear how this data was aggregated from year to year into the 2020 census tract boundaries. Finally, some of the data was not well defined. For example, the EJ Index data from the EPA included information on low-income percentage but it is unclear if this is in relation to median incomes of the area or something like federal poverty level.

Project Closeout

Completing this project has taught the author many valuable lessons. There were great lessons in project management and setting deadlines. The author also used to learn ArcGIS Online which was somewhat more restrictive than ArcGIS Pro. They learned how to navigate government websites to get data, specifically the Census Bureau's Data Portal which can be confusing at first to attempt to use. Perhaps the greatest lesson that was learned is that data collection is much harder than one thinks. Originally, the author thought that it would not take very long at all to find and aggregate data. However, this turned out to be one of the most time-consuming parts of the project. Allocating more time to this process is essential for future projects. Finding documentation on the data once acquired also proved to be a challenge in points. Another big takeaway is to prioritize and stick to deadlines to avoid crunch and late work.

The project overall was a success. The end result and deliverables are fairly close to the original conception minus the three dropped indicators. These indicators did not greatly affect the overall product. In fact, even more deliverables were able to be produced than originally planned for, mainly more detailed maps. The maps, spreadsheets, and script delivered were of high quality and captured the original goal of identifying disadvantaged census tracts. All these factors combined make the project a success.

There is lots of room for future work regarding this project. One would be to add back those dropped indicators by aggregating the block group data into data for the census tract level. Another improvement would be to add more indicators based on additional research, particularly transportation focused ones. The other natural extension of this work would be to aggregate more data sets. Preferably data sets would be consistently aggregated at the county level. Then once a state's county sets are completed, a state data set could be compiled and so on until a national data set is acquired. This is ideal because the analysis can then be done on three different scales of analysis, at the county level, state level and national level. It would then be interesting to compare the results at the different scales and look for patterns. Finally, an area that could be improved is the speed of producing data sets. It is unclear how to speed up this process but a way to do so would be ideal considering the amount of time it takes to aggregate one county level set.

Conclusion

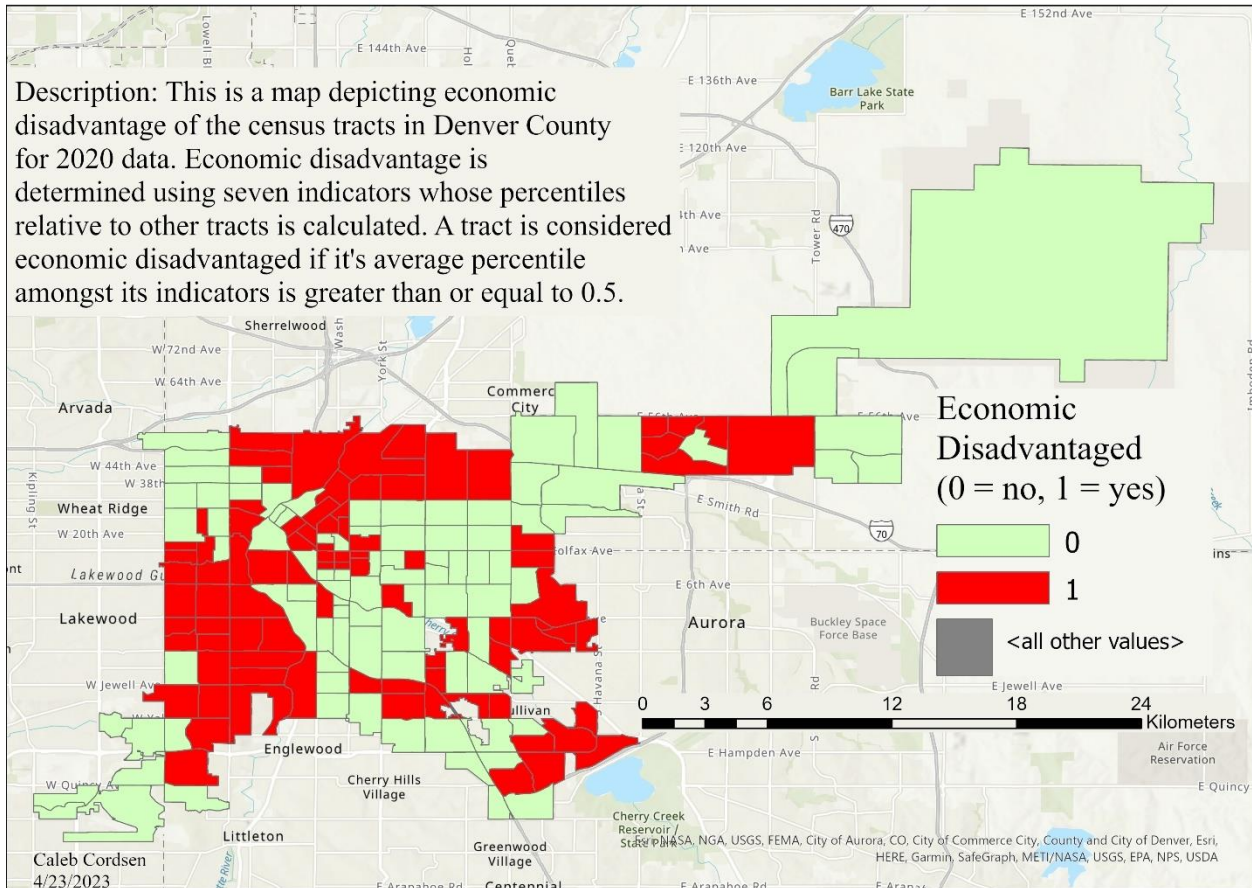
The goal of this project was to identify census tracts that were overall transportation disadvantaged and see where transport exists. This project successfully delivers many different

forms of media that convey the answer to this question. The author feels confident that this goal was accomplished.

Appendices

Appendix A

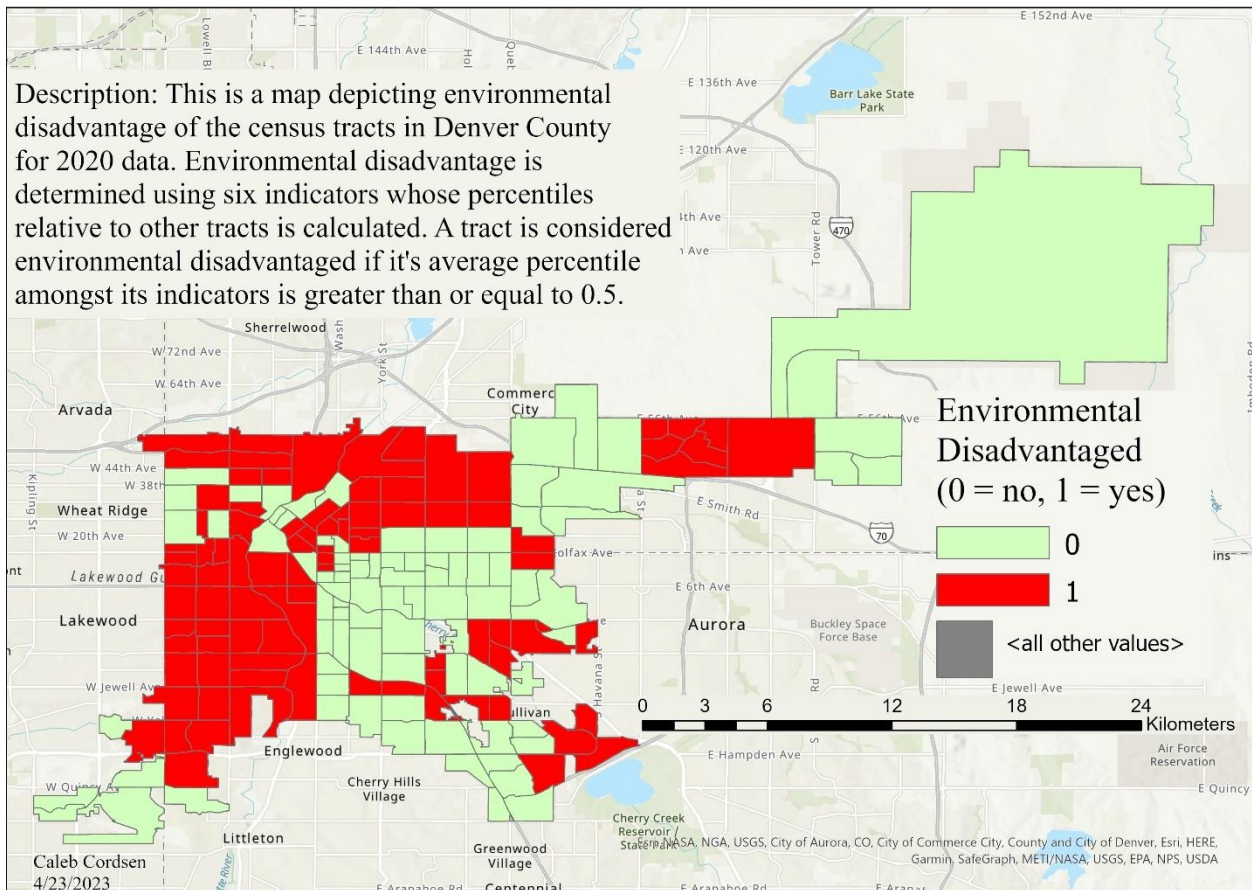
Denver County Economic Disadvantage



This appendix displays a map that shows economic disadvantage in Denver County.

Appendix B

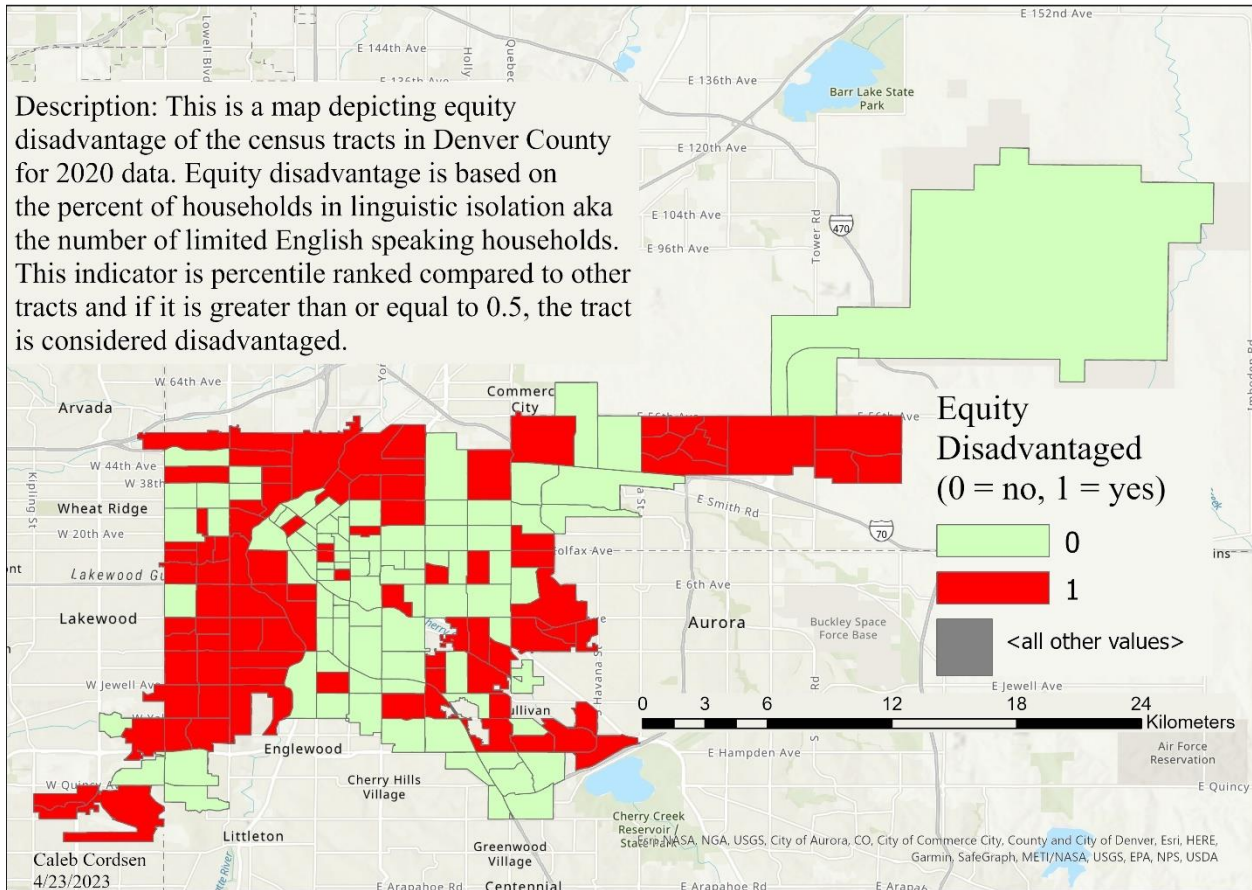
Denver County Environmental Disadvantage



This appendix displays a map that shows environmental disadvantage in Denver County.

Appendix C

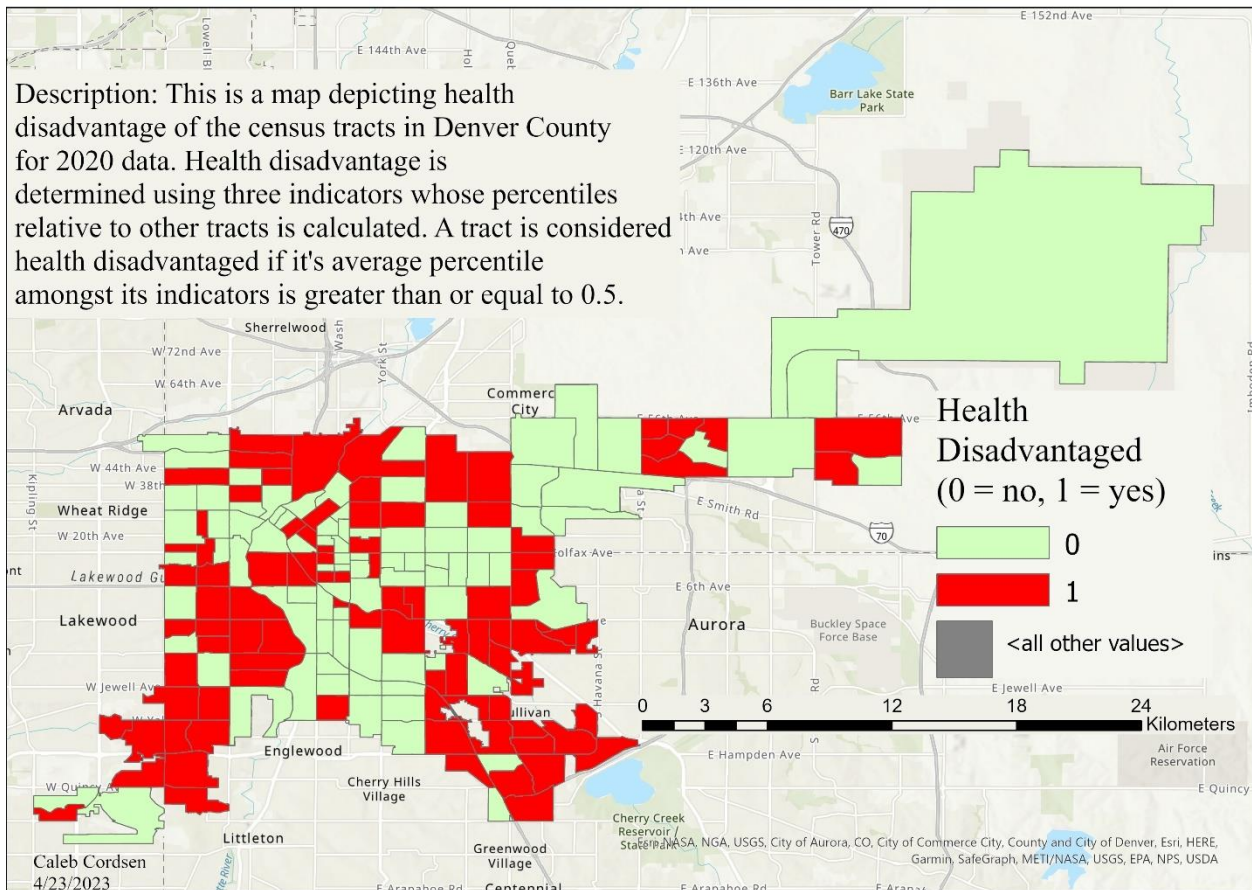
Denver County Equity Disadvantage



This appendix displays a map that shows equity disadvantage in Denver County.

Appendix D

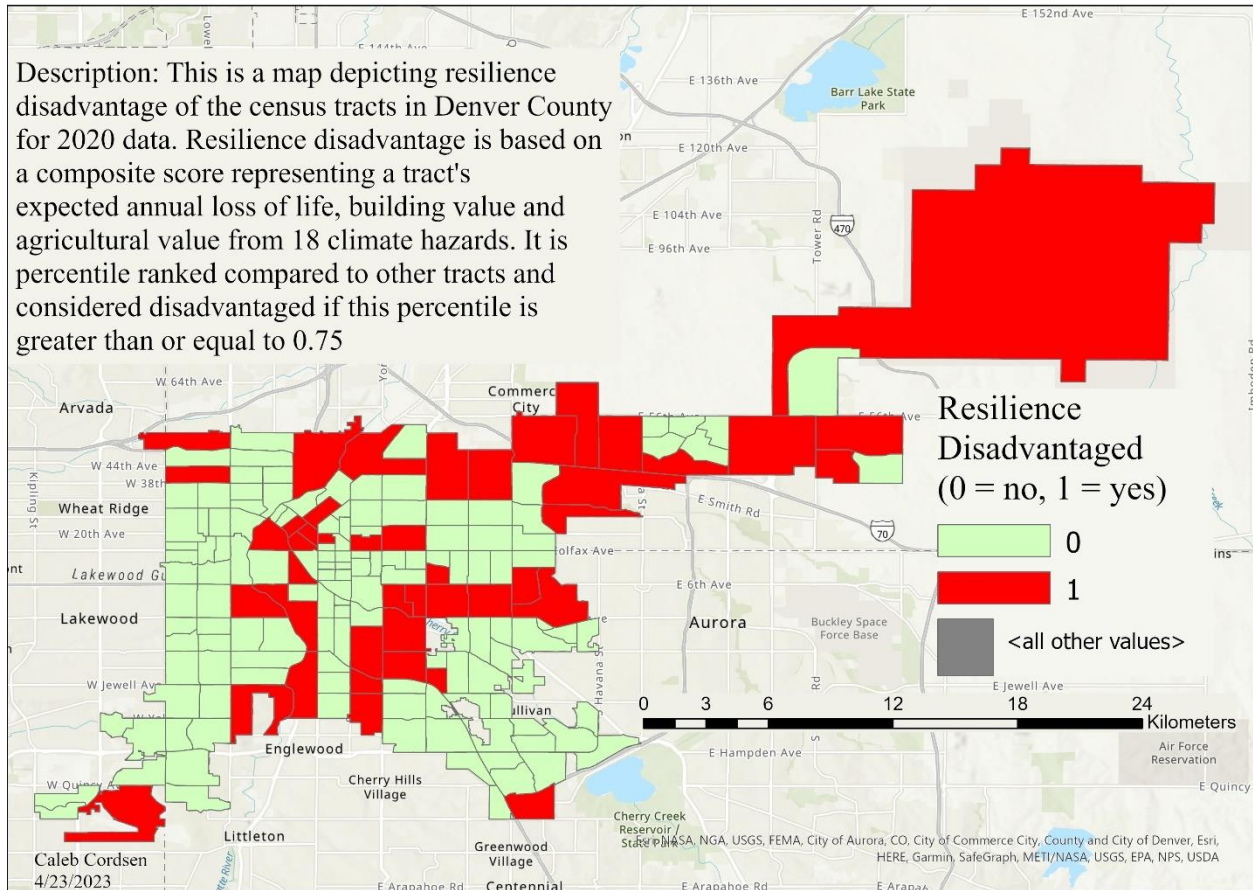
Denver County Health Disadvantage



This appendix displays a map that shows health disadvantage in Denver County.

Appendix E

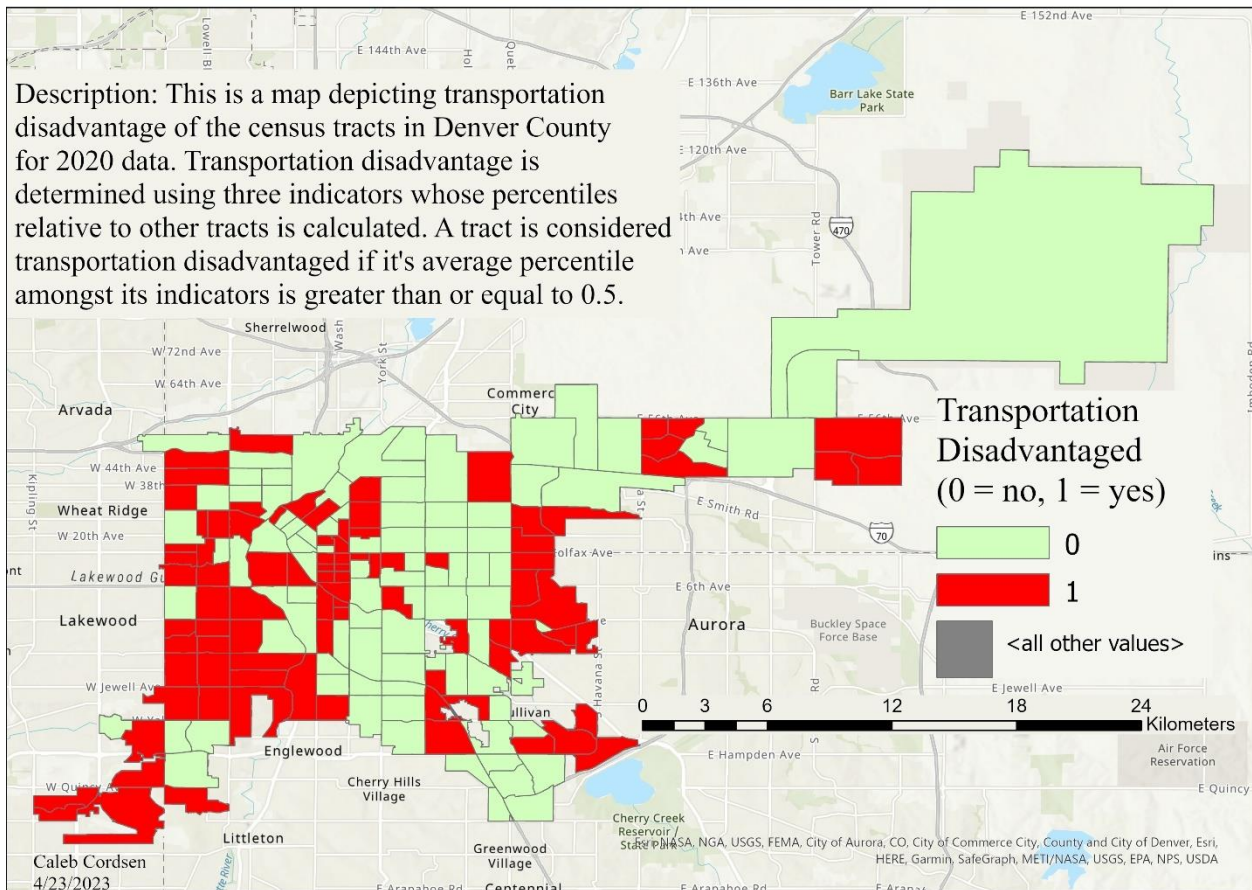
Denver County Resilience Disadvantage



This appendix displays a map that shows resilience disadvantage in Denver County.

Appendix F

Denver County Transportation Disadvantage



This appendix displays a map that shows transportation disadvantage in Denver County.

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