GEOG 578: GIS Applications 2018 Spring Semester

TWIN CITIES LTR EXTENSION: PURPLE LINE

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(1.0) Capstone Statement

The 2004 introduction of the light rail transit system to the Twin Cities area has quickly become the most cost-efficient mode of transportation for residents. The continued success of the light rail has prompted the Metropolitan Council to explore expansion opportunities, with emphasis being put on equity and future development areas, as stated in their Thrive MSP 2040 master plan. To create an optimal route, we will be proposing a metro light rail extension using weighted raster sum overlay and cost path analysis.

(2.0) Background

Our project is concentrated within the Twin Cities Metro Area. This area, governed by the Metropolitan Council, contains 7 counties and over 90 cities. Although this area encompasses over 900 square miles, our analysis is focused more closely on the Twin Cities themselves, Minneapolis and St. Paul, as existing transit hubs are found there (Metro Transit 2017 Facts). Around the world, millions of commuters rely on public transit as their primary source of transportation, to and from city centers. To extend public transit availability to those underserved in the Twin Cities Metro Area, we have proposed a new purple LTR route focused on equity and future development. Successful introduction and adoption of the purple line can be extremely beneficial for the entire state of Minnesota. The purple line has the potential to attract new economic investment while providing essential mobility to workers, students, and other commuters. In addition, the purple line will ease highway and other road congestion, helping alleviate the regions carbon footprint as LRT produces no emissions. Most importantly, our new purple line will provide transportation to those currently not served, helping connect those individuals with the heart of the Twin Cities, providing them with new opportunities and helping new areas flourish. This final point is consistent with the major goals of the Metropolitan Council's Thrive MSP 40 Master Plan (Garrett, 2015).

In 2017, total Metro Transit ridership (including buses) topped 82 million; LRT accounted for nearly a third of that ridership. During this year, the blue line and green line both saw record ridership levels at 10.7 million and 13.1 million, respectfully. Although LRT ridership continues to increase, over 75% of the Twin Cities Metro Area's workers currently drive alone.With public transit only accounting for 5% of worker's means of transportation, LRT remains largely untapped in the region. The introduction of the purple line is capable of providing the state of Minnesota with further economic and environmental benefits (Metropolitan Council, 2016).

Following this section, the reader will find information related to the design of our research and the structure of our argument. Sensitive sites are areas we want our LRT route to avoid and will be explained later in detail. In addition to sensitive sites, we will be looking at trip origin and destinations, rider demographics and transportation nodes to determine the most suitable route for the purple line. Decision making, including the operationalization and implementation of variables and their rankings will be justified with the use of scholarly sources. Graphics displaying the purple LRT extension will be included along with an analysis of the line and the area that it serves. The report will conclude by addressing our project goals stated previously in our capstone statement. The future research section will include any additional data, variables, operations, or analyses that may further our understanding of our research question.

(3.0) Methodology

Developing a transit system that can serve a large population in an efficient and equitable manner is essential to the growth and prosperity of any region. However, there are countless transit modes to choose from and millions of residents to please. Even in the case of this project where only LRT has been selected for analysis, the exponential number of possible expansion routes quickly becomes overwhelming. Despite this, by highlighting variables of a successful light rail route and combining those variables, we were be able to unearth a potential LRT expansion route for the Twin Cities Metro Area.

There are many things to consider when planning for the development of a light rail line and some features are more important to consider than others. Therefore, we conducted a weighted raster sum overlay analysis to locate suitable areas for LRT routes. Weighted raster sum overlay was selected as it allowed us to prioritize equity and future development while still considering other variables. All of our data layers were originally in vector format, so it was necessary to convert all of our layers from vector to raster before the raster overlay could be performed. Additionally, we reclassified all of our data classes using constant scale of 0-100 with 0 representing the most suitable location. The following section will outline why we selected 15 variables that contribute to a successful LRT route in the scope of our project and how we utilized them to find the optimal roue. A conceptualization and implementation diagram highlighting the workflow we followed can be found in appendix A and B. Our variables fall into four key concepts: sensitive sites, trip origin and destination, rider demographics, and transportation nodes.

(3.1) Sensitive Sites

When considering where to run a LRT line, it is logical to first consider where you would not want the line to go through. These areas can be spaces where it is physically impossible to construct a station or areas that hold significant environmental or social importance. Places such as “cemeteries, parks, wetlands, and other sensitive areas” should generally be avoided (Jha, Schonfeld, and Samanta 2007, 162). Considering the geography and history of the Twin Cities region, we selected four variables that are important to avoid when planning LRT routes: primary schools, bodies of water, historic sites, and parks.

Primary Schools have been identified as areas to avoid in the construction of LRT routes. Schools are structures that often hold social and cultural significance. Families choose where to live based off what schools are in the area, “one in four families have moved address to obtain a school place for their children” and would be rightfully upset if a LRT line lead to school closures and possible district restructuring (Adams 2017). The Met Council has point locations of all school program locations under their jurisdiction. First, we had to clip the school locations to the boundary of Met Council authority. After running an attribute query, a new shapefile was created that included only the locations of primary school buildings. Additionally, a 500 ft buffer was placed around each school to simulate the average size of a school and a 300 ft buffer was added to mark the additional area required for the creation of a school zone (MN Department of Children Families and Learning 2003). Only primary schools were selected for analysis because sites of secondary education are included in the activity centers data layer and primary school attendees are the demographic group that uses LRT the least. When reclassifying the raster cells, a cell that contained a primary school received a score of 100. All other cells received a score of 0 as they are in spaces that aren't inhibited by a school.

Although the official number is closer to 12,000, the state of Minnesota is known as the land of 10,000 lakes, which poses a problem for the construction of a light rail. Whereas it is not impossible to construct a LRT line on a body of water the idea is illogical and would be extraordinarily expensive. Therefore, we will avoid including "bodies of water" in our station analysis through the use of boolean scoring. Rivers posed a problem to the functionality of running our cost path analysis, therefore an attribute query was used to remove them from the analysis. To ensure the LRT route doesn't deteriorate the waterbody we created a 300 ft buffer around each water feature. The increment 300 ft was chosen in order to remain consistent with our school zone buffer in our primary school data layer. Lakes are often areas of recreation as well, so a 300 ft buffer will allow a potential LRT station to be within walking distance. When reclassifying the raster cells, a cell that contains a body of water received a score of 100. All other cells received a score of 0 as they are in spaces that aren't inhibited by water. We used the Open Water Features shapefile provided by the Metropolitan Council to incorporate lakes into our analysis.

Although citizens utilize public transportation to enjoy parks, the recreation spaces themselves shouldn't be destroyed to create a LRT route. To discourage a park from being in the line of our proposed purple line, we used the Met Council's Regional Parks data layer and added a 300 ft buffer to each polygon. When reclassifying, the raster cells that are part of these park areas will be given a score of 100. All other cells will be given a score of 0 as they would be considered suitable sites for a LRT line.

The state of Minnesota has 26 recognized historic sites and museums, 8 of which reside in our study area. These areas of cultural pride and historical education must be preserved when planning and developing new transit. Since we were unable to obtain GIS data for these areas, we digitally recreated historical sites as our original data layer. Utilizing satellite imagery from Google Earth, we were able to obtain close up images of the 8 historical sites. First, placing control points and recording their coordinates, we were able to export the imagery as a JPEG file. After uploading the JPEG files into our GIS software, we were able to georeference the imagery with the utilization of the control points. Once the imagery was georeferenced, we manually digitized polygons around the areas of interest, saving the polygon as its own feature. Staying consistent, a 300 foot buffer was placed around the 8 polygons, helping deter the possibility of any degradation to these historic sites. All 8 historic sites were then placed into a single layer which gave the historic sites a score of 100 and all other areas a score of 0 (Minnesota Historical Society).

(3.2) Trip Origin & Destination

After determining locations that aren't suitable for LRT line construction you can begin to think of what characteristics make LRT stations or routes attractive. LRT stations are the places that riders either start or end their trip, so it is essential to think about what locations people travel to and from most. The three spaces that people visit most often are generally their homes, their places of work, and recreation spaces. Therefore, it would make sense that LRT stations locate as close as possible to these venues. When studding the factors influencing Metro station ridership, Zhao et al. found that population, employment, major education buildings, entertainment venues, and shopping centers were all significantly related to Metro station ridership (Zhao et al. 2013, 123). For a LRT project to be economically viable and provide access to both current and future populations, these variables must be taken into consideration. When characterizing trip origin and destination we considered three variables: activity centers, 2040 employment density, and 2040 population density.

Activity centers are places people go to recreate, enjoy entertainment, and socialize. These spaces often consist of restaurants and bars where people consume alcohol, making it important that public transit is within walking, not driving distance. For our activity center data layer, we used the Met Council's point file of regionally recognized nodes or corridors where people shop, recreate, or are entertained. The closer an LRT line or station is to these centers, the better. Because of this we used fuzzy scoring and euclidean distance calculations to prioritize locations close to activity centers. It is important that people are able to walk to these locations, so we factored in a catchment area of one mile. The first overlay we completed only displayed values in the activity center areas. Because of this, it was necessary to merge the activity center shapefile with a shapefile that corresponded to the Met Council boundary. Following this merge we placed a multi-ring buffer around the activity centers using the distance breaks used by Guerra et al: 0.25 mi, 0.5 mi, 0.75 mi, and 1.0 mi (Guerra et al. 2012, 106). This aligns with a study done on the distance people are willing to walk to LRT stations which found that "no one walked farther than 1750m (1.09mi)" (O'Sullivan and Morrall 2003, 19). Fuzzy scoring allowed us to prioritize the areas within a quarter mile of activity centers, but not exclude the spaces just outside this range. Scoring for the buffered areas can be found in the conceptualization and implementation diagram in appendix A and B.

Running a LRT route through areas of high population and employment density helps ridership remain high. If someone is easily able to get to and from work using the light rail they are much less likely to drive, and the benefits associated with light rail can be captured. A large part of any transportation project is ensuring that the services that are built serve populations in the future. You don't want to build a light rail out to an area that is expected to drastically decline over the next 20 years. Because of this and the Met Council's desire to focus on future development areas we created two data layers representing future growth: 2040 population density and 2040 employment density. The year 2040 was chosen as the year of analysis because it is the farthest projection made by the Met Council. The Met Council has created 3,030 official Transit Analysis Zones (TAZ) encompassing the metro area. Using this shapefile, we first clipped the TAZs to the Met council boundary, then populated a new field that represented density due to the varying sizes of the TAZs. Natural Breaks (Jenks) was used to classify the 2040 projections and was used throughout the project for all classifications that were not distance based or containing a set classification schema. The class with the highest density received a score of 0 and the remaining classes increased in score by 20.

(3.3) Rider Demographics

To build a successful transit system, it is essential to build a basic understanding of who is riding current public transportation systems, as well as who you are aiming to serve with potential future transit expansion. Referencing existing LRT lines and utilizing the Metropolitan

Council's Thrive MSP 2040 Transportation Master Plan, we have identified demographics likely to support a healthy and effective rail expansion. Further improving the equity of the light rail transit lines by serving neighborhoods currently underrepresented by existing lines (Met Council 2014). Among groups underserved by light rail lines currently in use are minority populations in the Twin Cities area, as well as those whose median household income doesn't meet the Minnesota average. Other main characteristics of riders using light rail transit are specific age groups, and those who do not own a car and rely on the light rail to get them to where they need to go.

One goal of the Thrive MSP 2040 plan is to cater to areas with a greater than 50% non-white population (Metropolitan Council 2014). A quick look at the Twin Cities Metro Area using census data shows us that this goal, while admirable, is a bit ambitious in the homogenous region in regards to white population (Statistical Analysis 2018). Using American Community Survey data at the block group level an SQL query was performed to find the percentage of minority population in an area. Five classes were created using the same classification breaks the Met Council used in their Thrive MSP 2040 plan. Areas with a higher percentage of minorities receive lower scores. Specific classification and fuzzy scoring can be found in the conceptualization and implementation diagram in appendix A and B.

Areas of low median household income are also stated in the Thrive MSP 2040 plan and receive the most attention in the creation of new projects (Metropolitan Council 2014). The treatment of groups earning low incomes is of serious concern and must be remedied by new project proposals. The latest American Community Survey data shows that the median household income of Minneapolis and the surrounding area is $54,571 (Data USA 2018). New initiatives highlight the necessity of catering to those earning less than this amount. Fuzzy scoring was used to place those earning the lowest as the most important for receiving light rail lines closest to them. Five classes were created using the income breaks used by the MinnPost cartography team (Berg, 2018). Specific classification and fuzzy scoring can be seen in the conceptualization and implementation diagram in appendix A and B.

A successful light rail expansion aims to appeal to those who are most likely to provide the highest ridership numbers. Moving away from equity, we looked at the age of the average rider of light rail transit. We created a 5-class system using data from the American Public Transport Association (APTA) regarding rail transit user data from 2017 (American Public Transport Association 2018). According to APTA, the age group that has the highest ridership percentage is the 25-34 age group. To target these residents we ran a SQL query to populate a field that represented the percent of the population in the 25-34 year old age demographic.

The last demographic we will take into account will be auto ownership. For households with no vehicles, public transit is the only way to navigate the city. Because of this we targeted zero vehicle households by running a SQL query to populate a field that represented the percent of households without a vehicle. Lower scores were given to areas that had a higher percentage of households with no vehicle. Our hopes are that in appealing to those without other modes of transportation, we can ensure that ridership on our new route will be as high as possible.

(3.4) Transportation Nodes

The Twin Cities area is already home to an extensive transit network consisting of light rail lines, bus lines, bike lanes, and park and ride lots, among others. These transit systems allow citizens to reach distant lengths of the area with relative ease. Our light rail extension proposal can utilize these transit systems currently in place to maximize its reach to areas much further than what it can cater to alone. Placing stations near other transportation nodes will allow transfers to and from our light rail extension, and thus ensuring its effectiveness and overall success.

Bus routes currently in use contain the highest ridership numbers of any transit option in the Twin Cities. Bus ridership numbers in 2017 alone reached over 55 million (Rail Ridership 2018). Placing light rail routes near bus stations will allow for riders to use bus routes to connect to our purple line, thus extending the usefulness of our line by immeasurable numbers. An attribute query was used on a Met council transportation network shapefile to isolate existing bus routes. After clipping the routes to the Met Council boundary, a multi-ring buffer was placed around the bus routes with the same distance brakes and scoring used for activity centers.

The bike route system is extensive in the Twin Cities as well, and the fact that every light rail station has bike racks encourages bikers to use light rail transit. Bikers will likely ride straight to the stops from the routes, but to keep things uniform, we used the same scoring scheme as bus routes. Multi-ring buffers were created around the existing bike routes after clipping the routes to the Met council boundaries. Keeping the LRT line close to bike paths also promotes bike use and an overall healthy population, another great reason to keep them in consideration.

Park and Ride lots provide commuting access for those who live too far to take advantage of exiting transit systems. Current park and ride spots are in place for bus systems as well as light rail specific lots, like the blue line lots located at Fort Snelling and 28th Avenue (Park & Ride 2018). The current success of lots near the blue line shows the potential to continue the trend in lots unserved by current light rail line and would expand the potential of the new line into the distant suburbs where it would be ineffective and inefficient for the line to serve them directly. Multi-ring buffers were places around the point features to prioritize areas close to park and rides. Again, we used the same scoring system for Park and Ride lots as for our other distance based layers.

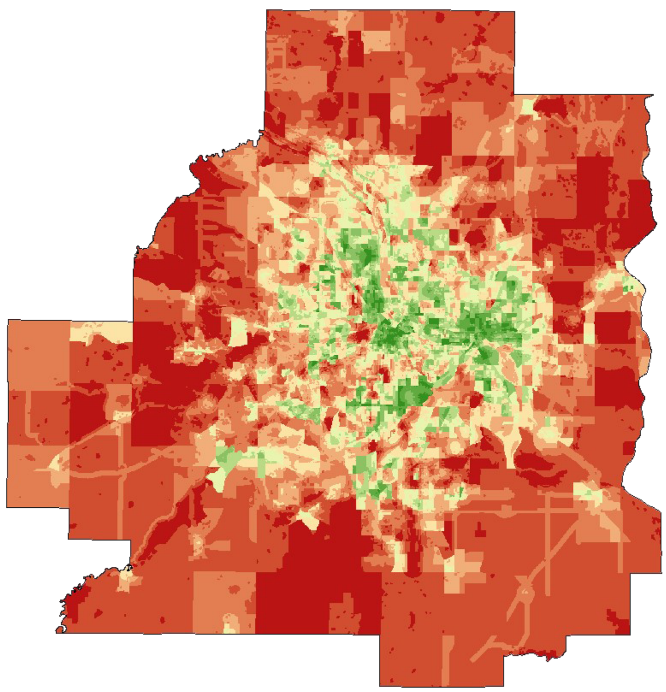
Existing light rail transit lines are highly important to the success of our project proposal and have been referenced many times in the process of creating variables justifying LRT placement. These lines do a fantastic job serving the areas they currently inhabit, so we will be looking to further this success by extending to areas unserved by current light rail lines. Our line will extend from the Union Depot in St. Paul to ensure connections between the green and blue lines. Other than this, we wanted to avoid running our line in areas already served by these two lines, and thus we placed a multi-ring buffer around the current and future lines to discourage our line from locating in those areas. We also included BRT and commuter rail routes in this layer because they already have established infrastructure. The same distance breaks were used to create our buffers, but the scoring was inverted so that areas close to the lines correspond to higher scores.

Most light rail routes and stations reside on existing roadways. They are not all encompassing of light rail lines, as some are located on abandoned rail lines and walkways within the city. Nonetheless, roads are the majority and were our main focus when considering route locations for our light rail extension. In order to ensure our line ran on or alongside the road network of the Twin Cities, we first clipped the road network to the Met Council boundary then created a ten meter buffer around the roads. Ten meters was chosen as the buffer size because the average size of a road lane is 3m (Federal Highway Administration). The functional class roads shapefile we used for our road network contains roads with 2-8 lanes. A ten meter buffer allowed us to account for roads of up to 6 lanes, which is the largest road size a current light rail runs on. The roads layer was not included in our raster overlay, but instead used to clip our final output and therefore it did not need to be scored.

The final phase of our project involved overlaying our raster layers then running the cost path analysis. The weighting schema used to overlay the layers can be found in appendix C. We chose to give the highest weights to our equity and future development variables as they addressed our project goals. Large weights were also given to activity centers because the are essential for LRT ridership and existing LRT, BRT, and commuter rail lines to ensure our new line serviced underserved populations. After we received the output of the weighted raster sum overlay it was necessary to clip the raster to our road network polygon to ensure the line ran on or near a road. Finally, to locate the physical path of the LRT line a least cost path analysis was used. The least cost path process "records the least-cost path or paths from selected locations to the closest source cell defined within the accumulated cost surface, in terms of cost distance" (ESRI). To get the cost path to run, cost distance and cost distance backlink rasters must first be created. It also requires the selection of start and end points. These points were selected after review of the weighted raster overlay. The completion of the weighted raster overlay and cost path analysis allowed us determine the optimal LRT extension route according to our project goals.

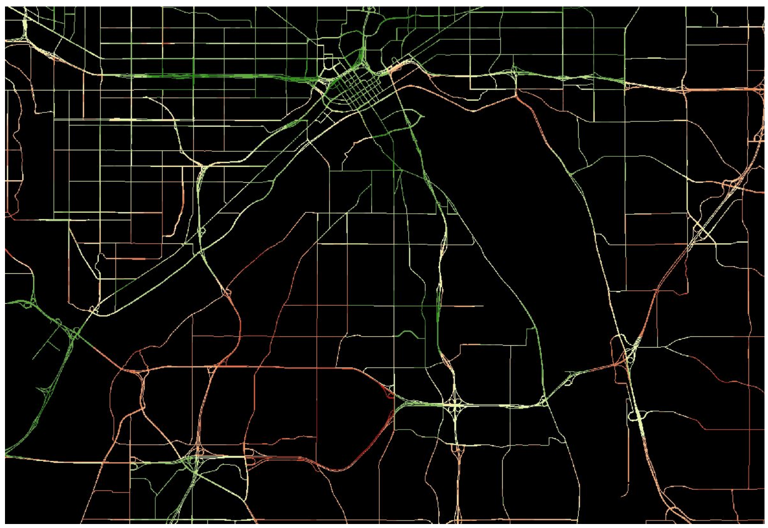
(4.0) Results and Analysis

After scoring all of our layers and defining the weights, we ran them all through a weighted raster sum overlay. The tool produced the output seen below in figure 1.



[Figure 1: Output of weighted raster sum overlay.]

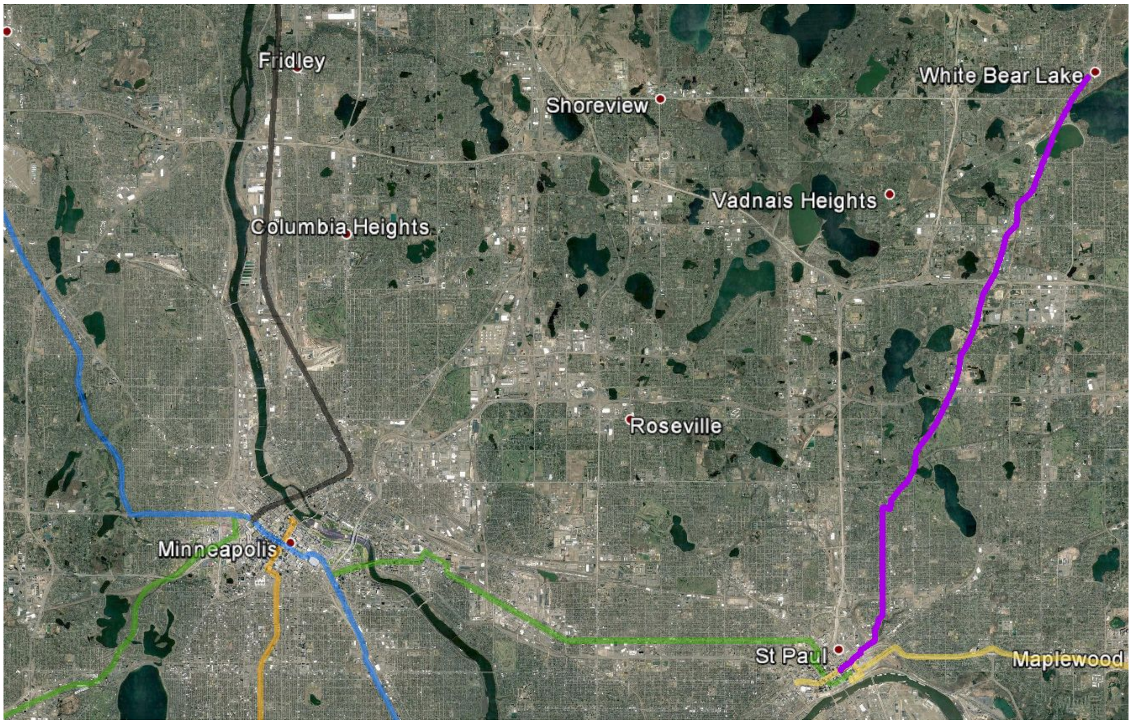
The greener areas are the areas that scored the lowest in the overlay, which corresponds with the most suitable areas for expansion, while the red areas are those that scored the highest and were generally avoided when we ran our cost path analysis. The large concentrations of green are located at the centers of the two major cities in the study, Minneapolis and St. Paul. Population and employment density in these areas are very high, and they scored very high in other categories with heavy weights including percentage non-white, activity centers, and households with no cars. There are other hotspots in our overlay analysis, and some of these are outliers due to the nature of the data we used, including the false green score for the Minneapolis-St. Paul International Airport in the south-central part of the study. The clipped roads buffer layer with the weighted raster sum overlay can be seen in Figure 2 below.



[Figure 2: Output of weighted raster sum overlay clipped to the road network]

The image is of the St. Paul area and shows only the roads our light rail extension can travel on, with their corresponding values that were determined by the weighted raster sum overlay. Green roads are preferred again in this picture.

Choosing an origin and a destination allowed the cost path analysis tool to compute the optimal route for our light rail extension, and the result can be seen in Figure 3 below:



[Figure 3: Proposed purple line on satellite image of the Twin Cities.]

Our proposed purple line starts at the Union Depot in downtown St. Paul and ends near a park and ride in downtown White Bear Lake. The line runs around 11.3 miles to the northeast and passes through three different cities: St. Paul, Maplewood, and White Bear Lake. In St. Paul, it follows two different streets, 5th St. and Edgerton Street, while Maplewood Dr. and Hwy 61 are the roads followed by the light rail in Maplewood and White Bear Lake respectfully.

Our starting location was chosen to be the Union Depot in St. Paul due to the fact that is a major transportation hub in the area. Another light rail line, the green line, has a stop there, as well as the proposed bus rapid transit gold line, which means that the new line would be connected to each of their networks. St. Paul is also a major economic center of the region which has thousands of workers commuting to its center business district daily, and scored very highly in variables dealing with equity, including percent non-white, auto ownership, and median household income. White Bear Lake was chosen as the end stop for our line for its identity as a recreation hub, a commuter population, and the fact that there are no fast transit routes in the NE suburbs of the Twin Cities. It doesn't score very high in variables representing equity, but it is still an underrepresented area of the Twin Cities in regards to public transit that would benefit greatly from a line extension.

The least cost path goes through many different attractions, including two downtown centers, one large mall, the Maplewood Mall, and two smaller shopping centers. It travels through four different Park & Rides, which encourages its use as a commuting tool. The high population density areas of St. Paul and Maplewood are served, and many low-income families living in North St. Paul get serviced by the new line. The line also passes through areas with high rates of households without automobiles, which is a big indicator in the potential need for transit opportunities. These are all variables that were weighted strongly in our overlay, so it makes sense that the line would travel through these communities. A final map of all the current and planned major transit lines in the Twin Cities region, including our proposed purple line, overlaid on the weighted raster sum overlay output can be found in appendix D.

(5.0) Discussion

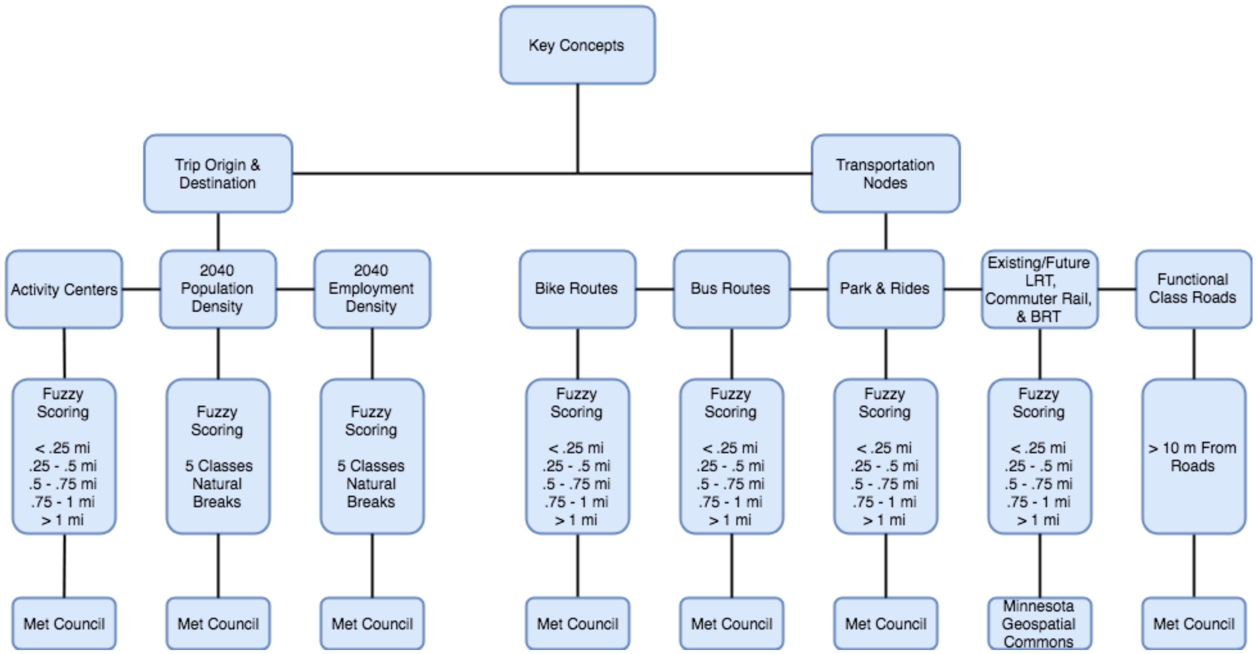
Due to the extensive nature of this type of project, a lot of variables have to be taken into account. The number of layers we included in our weighted raster sum overlay was high enough that certain layers ended up not being able to contribute much to the direction of the new purple line. An example of this can be seen towards the end of the line in White Bear Lake at Goose Lake. The line follows a road that goes through the lake. While the line could still follow this road, our analysis sought to discourage this by putting a buffer around the lakes. This buffer wasn't weighted strongly enough to discourage the cost path analysis from taking a route around the lake, which is not ideal for our light rail line and is something we would like to have avoided in our final output. Also, after our analysis, we saw other areas that would benefit greatly from an LRT expansion. It would have been nice to have alternate proposals for the Metropolitan Council to consider versus just the one line that we have in our current proposal.

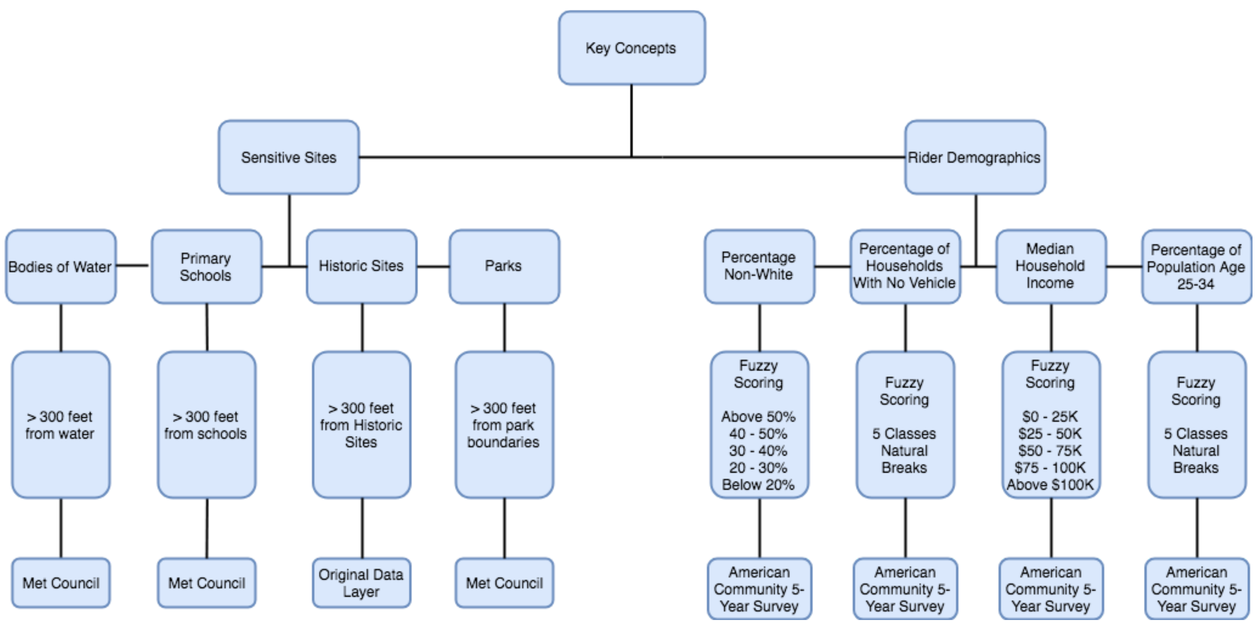
(6.0) Conclusion

When determining the best location for our purple line, many different factors were taking into consideration. However, in order to best coincide with the Thrive MSP 2040 Plan, the emphasis for line location was concentrated on equity and future development. Our new purple line helps provide transportation to those not currently served by public transportation in the Twin Cities Metro Area. Weighted raster sum overlay allowed us to strongly focus on layers related to equity and future development, while still considering other other important factors at lower weights. Once we generated our overlay and incorporated major existing and planned public transit routes, we were able to easily recognize our underserved area and implement our new purple line using a cost path analysis. With respect to future research, considering the cost of land is important towards the overall feasibility of the project. Considering the turning radius of the LRT would also be beneficial to ensure that the proposed route is feasible. While there are certainly a variety of approaches that could have been used to solve this geographic problem, we are happy with the results of our project and feel that the purple line is worth consideration in the future for the Twin Cities Metro Area.

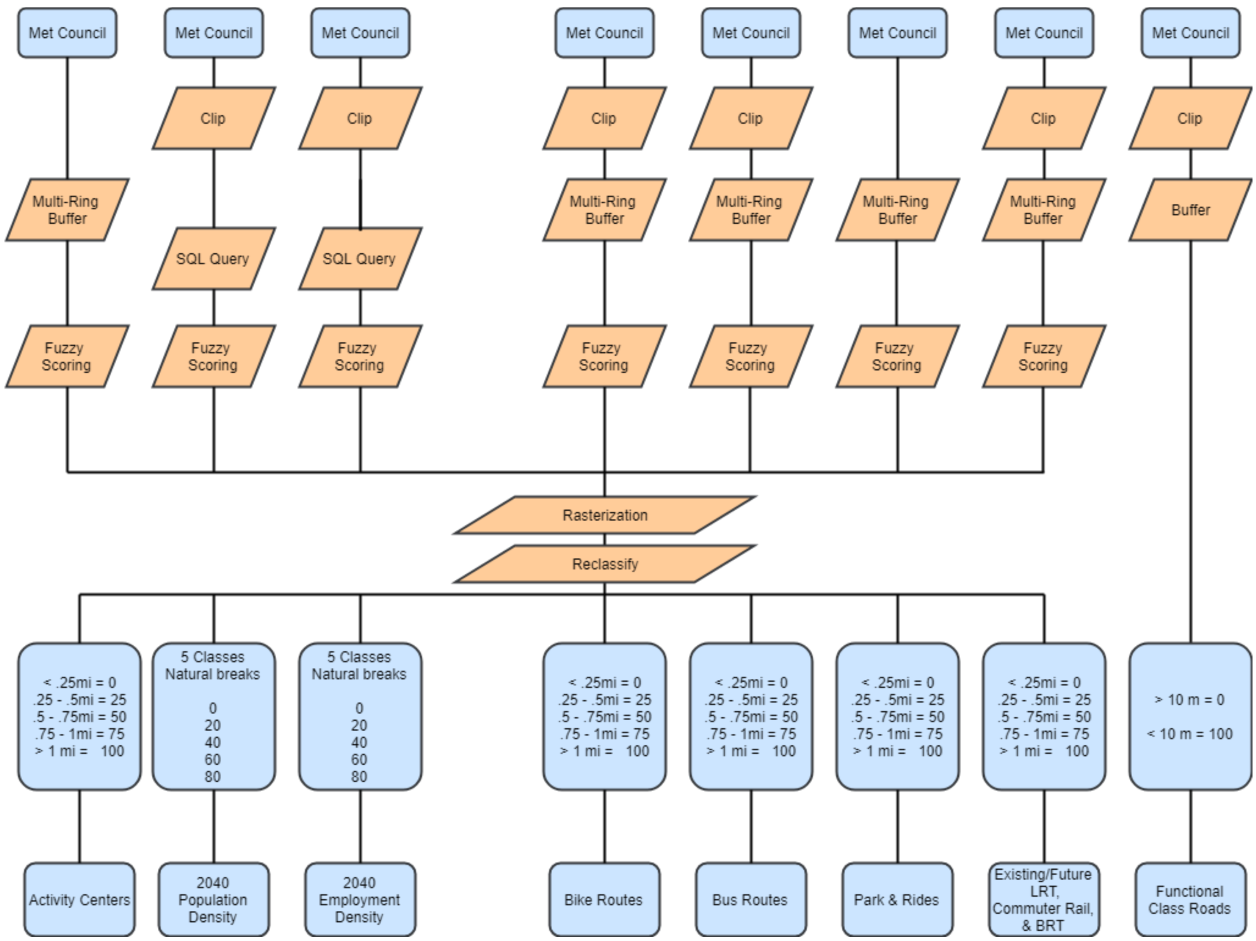
Appendix

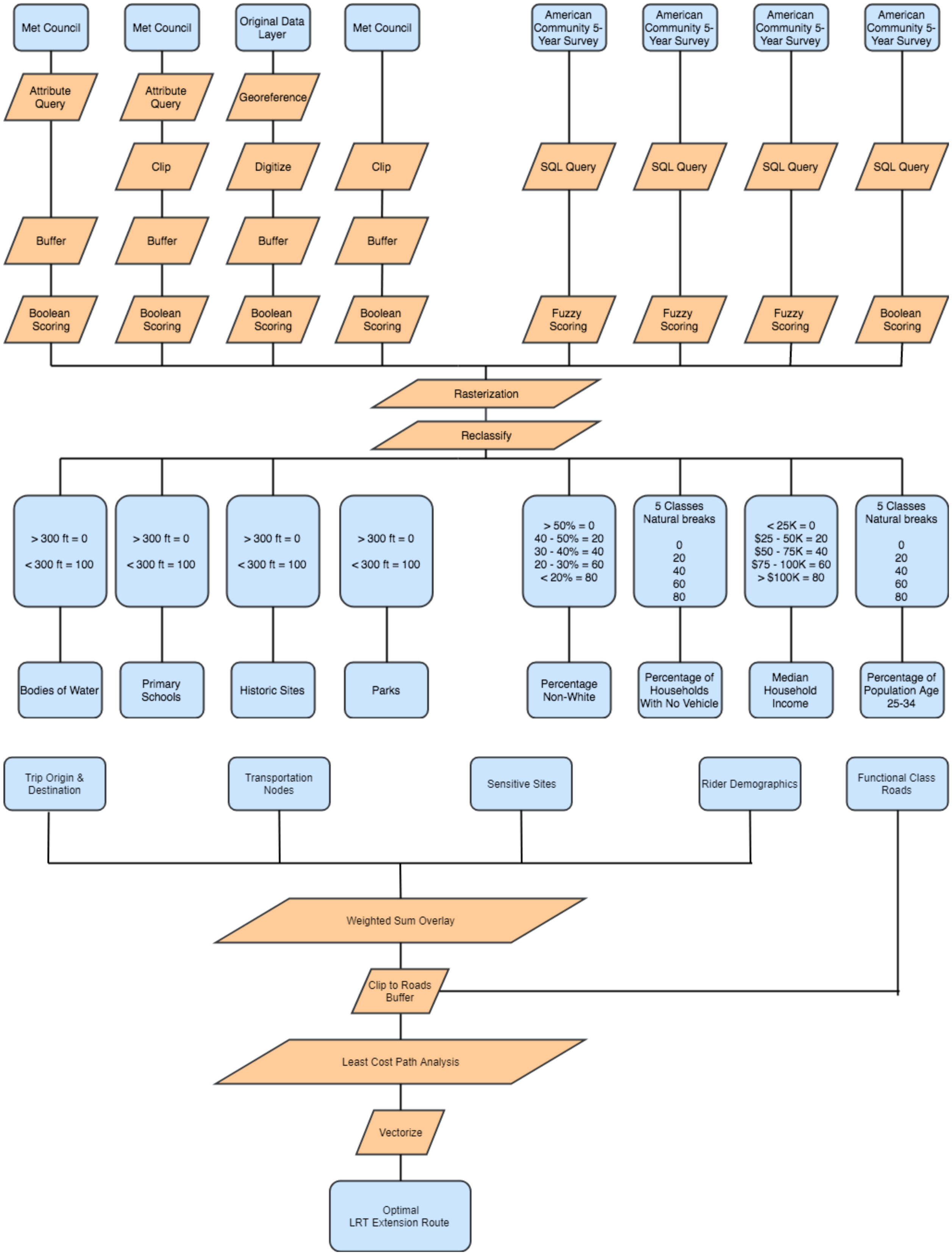
A) Conceptualization Diagram





B) Implementation Diagram

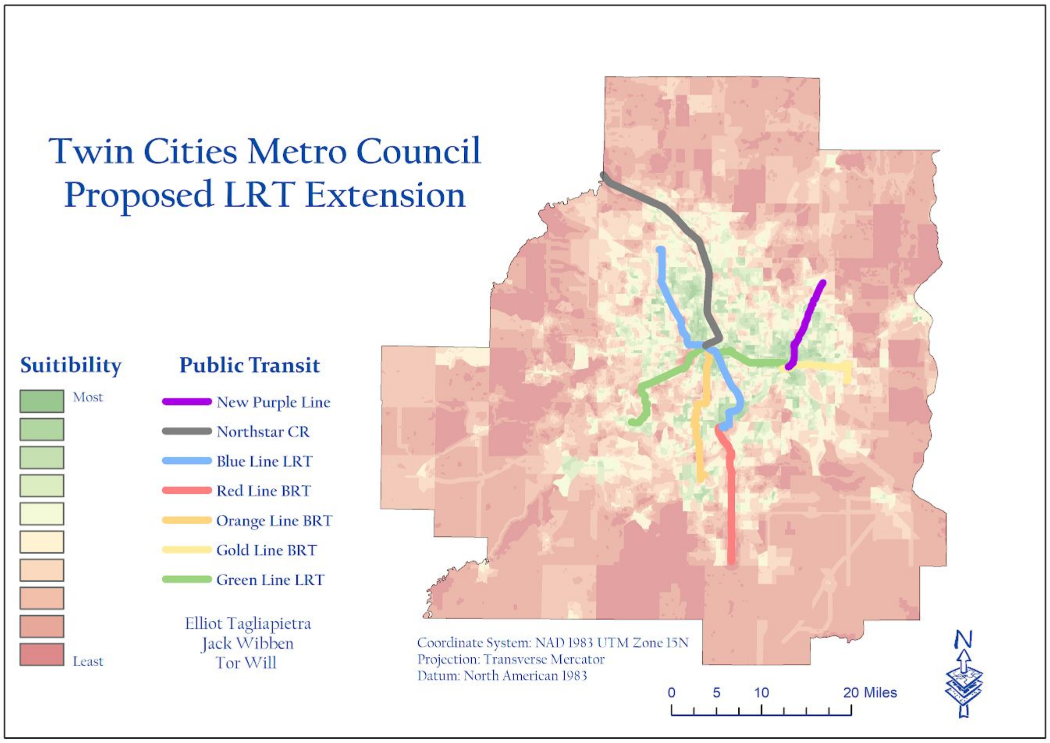



Met Council
Met Council
Original Data Layer
Met Council
American Community 5-Year Survey
American Community 5-Year Survey
American Community 5-Year Survey
American Community 5-Year Survey
Attribute Query
Attribute Query
Georeference
Clip
Digitize
Clip
SQL Query
SQL Query
SQL Query
SQL Query
Buffer
Buffer
Buffer
Buffer
Boolean Scoring
Boolean Scoring
Boolean Scoring
Boolean Scoring
Fuzzy Scoring
Fuzzy Scoring
Fuzzy Scoring
Boolean Scoring
Rasterization
Reclassify
> 300 ft = 0 < 300 ft = 100
> 300 ft = 0 < 300 ft = 100
> 300 ft = 0 < 300 ft = 100
> 300 ft = 0 < 300 ft = 100
> 50% = 0 40 - 50% = 20 30 - 40% = 40 20 - 30% = 60 < 20% = 80
5 Classes Natural breaks 0 20 40 60 80
< 25K = 0 $25 - 50K = 20 $50 - 75K = 40 $75 - 100K = 60 > $100K = 80
5 Classes Natural breaks 0 20 40 60 80
Bodies of Water
Primary Schools
Historic Sites
Parks
Percentage Non-White
Percentage of Households With No Vehicle
Median Household Income
Percentage of Population Age 25-34
Trip Origin & Destination
Transportation Nodes
Sensitive Sites
Rider Demographics
Functional Class Roads
Weighted Sum Overlay
Clip to Roads Buffer
Least Cost Path Analysis
Vectorize
Optimal LRT Extension Route

C) Weighted Overlay Weighting Schema

Raster Layer	**Raster Layer Weight (%)**
Percentage Non-White	15
Median Household Income	15
Percent of Households with No Vehicles	10
2040 Population Density	10
2040 Employment Density	10
Activity Centers	10
LRT, Commuter Rail, and BRT Routes	10
Percent of Population Ages 25-34	5
Historic Sites	3
Bike Routes	2
Bus Routes	2
Park & Rides	2
Bodies of Water	2
Parks	2
Primary Schools	2

D) Purple Line: Proposed LRT Extension



References

1. Adams, Richard. "One in Four Families Move House to Secure School Place – Survey." The Guardian. September 01, 2015. Accessed March 20, 2018. https://www.theguardian.com/education/2015/sep/02/one-in-four-families-move-house-to-secure-school-place-survey.
2. Berg, Steve. "Census 2010: Can a Metro Area so Sharply Divided by Income, Race and Geography Continue to Thrive on the National Stage?" MinnPost. Accessed May 04, 2018. https://www.minnpost.com/cityscape/2010/12/census-2010-can-metro-area-so-sharply-divided-income-race-and-geography-continue-t.
3. Guerra, Erick, Robert Cervero, and Daniel Tischler. "Half-Mile Circle." *Transportation Research Record: Journal of the Transportation Research Board*2276 (2012): 101-09. doi:10.3141/2276-12.
4. *Guide for Planning School Construction Projects in Minnesota*. Roseville, MN: Minnesota Department of Children, Families & Learning, Division of Program Finance, 2003. 66.
5. "Help." Understanding Network Attributes-Help | ArcGIS Desktop. Accessed May 04, 2018. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/cost-path.htm.
6. Jha, Manoj K., Paul Schonfeld, and Sutapa Samanta. "Optimizing Rail Transit Routes with Genetic Algorithms and Geographic Information System." *Journal of Urban Planning and Development*133, no. 3 (2007): 161-71. doi:10.1061/(asce)0733-9488(2007)133:3(161).
7. Minnesota Department of Transportation. "Passenger Rail." Rail Transit. Accessed March 20, 2018. https://www.dot.state.mn.us/passengerrail/railtransit.html.
8. "Mitigation Strategies For Design Exceptions - Safety | Federal Highway Administration." Safety Benefits of Walkways, Sidewalks, and Paved Shoulders - Safety | Federal Highway Administration. Accessed May 04, 2018. https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter3/3_lanewidth.cfm.
9. O'Sullivan, Sean, and John Morrall. "Walking Distances to and from Light-Rail Transit Stations." *Transportation Research Record: Journal of the Transportation Research Board*1538 (2003): 19-26. doi:10.3141/1538-03.
10. Samanta, Sutapa, and Manoj Jha. "Identifying Feasible Locations for Rail Transit Stations: Two-Stage Analytical Model." *Transportation Research Record: Journal of the Transportation Research Board*2063 (2008): 81-88. doi:10.3141/2063-10.
11. Zhao, Jinbao, Wei Deng, Yan Song, and Yueran Zhu. "What Influences Metro Station Ridership in China? Insights from Nanjing." *Cities*35 (2013): 114-24. doi:10.1016/j.cities.2013.07.002.
12. Metropolitan Council. “Chapter 6: Transit Investment Direction and Plan.” *Transportation Policy Plan.* Accessed March 20, 2018. https://metrocouncil.org/Planning/Projects/Thrive-2040.aspx

13. "Mapping Median Income Across Minnesota". 2018. *Minnpost*. Accessed March 20 2018. https://www.minnpost.com/data/2013/12/mapping-median-income-across-minnesota.
14. 2018. Statisticalatlas.Com. Accessed March 20 2018. https://statisticalatlas.com/metro-area/Minnesota/Minneapolis/Race-and-Ethnicity.
15. "Minneapolis, MN". 2018. Data USA. Accessed March 20 2018. https://datausa.io/profile/geo/minneapolis-mn/#num_vehicles.
16. "Who Rides Public Transportation". 2018. *American Public Transport Association.* Accessed March 20 2018. https://www.apta.com/resources/reportsandpublications/Documents/APTA-Who-Rides-Public-Transportation-2017.pdf
17. "Basics: The Spacing Of Stops And Stations — Human Transit". 2010. Human Transit. Accessed March 21 2018. http://humantransit.org/2010/11/san-francisco-a-rational-stop-spacing-plan.html.
18. "Rail Ridership Up, Overall Ridership Down At Metro Transit". 2018. Star Tribune. Accessed March 21 2018. http://www.startribune.com/rail-ridership-up-overall-ridership-down-at-metro-transit/471258614/.
19. "Metro Transit 2017 Facts." Metro Transit.. Accessed March 21, 2018. https://www.metrotransit.org/metro-transit-facts.
20. Garrett, Thomas A. "The Costs and Benefits of Light Rail." Federal Reserve Bank of St. Louis. January 13, 2015. Accessed March 21, 2018. https://www.stlouisfed.org/publications/central-banker/fall-2004/the-costs-and-benefits-of-light-rail.
21. "Communities." Metropolitan Council. Accessed March 21, 2018. https://metrocouncil.org/Communities.aspx.
22. " Park & Ride Lots - Metro Transit ". 2018. Metrotransit.Org. Accessed March 21 2018. https://www.metrotransit.org/park-ride-lots.
23. "Historic Sites." Minnesota Historical Society. Accessed May 04, 2018. http://www.mnhs.org/.