

Optimizing Bus Rapid Transit for Equity in Madison, WI

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Capstone Statement

In Madison, WI the 2016 Metro Transit annual report cites overcapacity as the leading detriment to the system's efficiency. This disproportionately affects low income, minority, and carless populations who rely on the transit system. The Madison Area Regional Transportation Plan 2050 has laid out a Bus Rapid Transit (BRT) system as a solution to this problem. Our goal is to implement a BRT plan emphasizing service to the origins and destinations of high density transit dependent populations. The final objective is an analysis of deviance between the MATPB plan and our own proposed route.

Introduction

Dane county is the fastest growing region in the state of Wisconsin and there is a desire to support this growth with improved transportation initiatives (MATPB "Regional ... Area" 2017, iii, iv). As a result, the Madison Area Transportation Planning Board's (MATPB) Regional Transportation plan cites the need for transit development based on the current and projected growth patterns in Madison and Dane County as a whole. The City of Madison has been working to implement a bus rapid transit (BRT) system for several years. For the purposes of this project, most comparisons will be made in reference to the most recent plan implemented in April of 2017, called the Regional Transportation Plan 2050, with some information derived from the previous plan, Regional Transportation Plan 2035. The regional plans are intended to set forth the goals for projected growth of multimodal transit (walking, biking, public transit, etc) in the Madison Metro Area. The intention is that further public transportation development is built on the foundations of social equity, environmental sustainability, and economic growth .

The key factors that define BRT are the ways in which it operates compared to a standard bus system and other forms of mass transit. Typically, BRT has a higher capacity than standard bus routes and will make fewer stops at higher frequencies. BRT is also a cheap alternative to the more conventional options of light rail (LRT) and heavy rail (subway). More importantly, it provides a higher threshold of flexibility for route updates and changes than would be afforded by the more cost prohibitive LRT and subway systems (VTA Transit 2007, 1-4).

BRT systems can be packaged in many formats. In its least developed form, BRT has a dedicated bus lane simply separated by solid lines painted on the road. In this scenario there is usually some component of mixed traffic, though ideally, the painted lane remains dedicated solely to buses. In highly developed forms of BRT there is more infrastructure dedicated to the operation of the system. This typically includes a lane separated from primary traffic through the use of raised dividers and stops that are easily identifiable. There is variability within the different versions of BRT. Some systems have lines that go through the middle of a major thoroughfare while separated from traffic by raised medians. Other versions are segmented away from regular traffic via raised dividers where the bus lane runs along the side of a road. In either case, stops have fully developed shelters with ticket meters and other amenities or raised platforms separating riders from the rest of traffic (Kittelsohn & Associates, Inc 2007, 1-1 to 1-5). For the purposes of this project we will assume that BRT implementation in Madison at least covers the minimum criteria explained above, having a painted line dividing the BRT from other traffic.

Our goal is to assess the proposed BRT lines laid out in the 2050 Regional Plan through a comparative analysis. As mentioned above, the key intentions of new transit development in Madison are that the system is built on social equity, environmental sustainability, and economic growth. Our focus is to assess the proposal on its effectiveness for promoting social equity. In other words, we assume the factors of environmental sustainability, economic growth and feasibility to be ideal. The route we develop optimally serves those that are most dependent on public transportation

including minorities, the poor, and carless households. It has been found that lack of access to transit exacerbates social exclusion, impacts people's ability to travel to work on time, accesses necessities like groceries, or simply to access social events (Lowe and Mosby 2-4, 2016). Next, we compare our proposed BRT route to the MATPB's proposed BRT route, while highlighting the differences. Thus, uncovering where the City of Madison could improve the equitability of the BRT plan or confirming that the plan is in fact optimized for equitability.

Methodology

In order to address this problem, we have devised a conceptualization diagram (Figure 1), which identifies the main characteristics needed to be able to establish an equitable BRT route. The key concepts that we used are target origins, target destinations, and road suitability. Each key concept consists of several variables that detail the specific features that make each key concept valuable. The variables then have specific parameters, which need to be fulfilled in order to create a feasible and equitable BRT line. Data was collected from a variety of different sources in order to operationalize those parameters. When developing our conceptualization diagram, we referred to the Bus Rapid Transit Practitioner's Guide, which states that key traveler information includes trip origin, destination, purpose, and socioeconomic characteristics (Kittelsohn & Associates, Inc. 2007, 3-1).

Target Origins

The first key concept is related to the origins of people who rely on public transit as their primary mode of transportation. This is where our equitable design comes into play, as we needed to determine the specific parameters that are associated with being transit dependent. Transit dependent individuals are those who are low income, have minimal car access, and are minorities. The last part was determining where these individuals live, which was done by ranking housing by levels of density.

Our first parameter is identifying census block group areas that are below 150% of the the local poverty level. According to the MATPB, the metric for calculating the poverty line of a typical family, being of two adults and two children, needs to be 150%

of that poverty line (Smeeding and Thornton 2015, 15). This is a valuable component because it identifies lower income individuals who spend a larger portion of their earnings on transportation costs (City of Madison 2017, 15-16). The population that falls below this line, are people who will most likely need to use public transit, which will help them save money and improve their access to other areas of their community. The second parameter that is a typical characteristic of a transit dependent individual is the lack of access to a personal vehicle. According to the City of Madison, the areas that are considered low vehicle access, are those where 15% of households or greater do not have access to a personal vehicle (MATPB 2017, Figure B-7).

The final parameter of a transit dependent individual is related to their race and ethnic identity. Minority communities are typically transit dependent, which is why it is pertinent to have reliable transit service for them. On average, black riders wait 40% longer than their white counterparts, showcasing the inequality of the transit system and the need for a more equitably distributed system (City of Madison 2017, 16). The City of Madison's Transportation Improvement Program calculated an area of high minority population by using two times the average minority population in the city. The average non-white population in the our study area was calculated to be 17%. Thus, areas identified as "high minority" have a minority population of 34 percent or greater, twice the average (MATPB "Transportation Improvement Program" 2017, 129). Along with race, the history of redlining has made it so these individuals are most likely to be renters in apartment buildings. Knowing the history, we made it so different residential types were ranked into high, medium, or low density residential.

Target Origins Implementation

In order to create a working layer for target origins, we first made decisions on whether fuzzy scoring or boolean queries were necessary in order to capture the areas of interest. Demographic information, including income, car access, and racial compositions, were collected using block group data from the U.S. Census Bureau. Income allowed us to determine the socioeconomic status of residents at the block group level. The income metric was fuzzy scored based off the poverty level. If a block group's median household income was greater than 150% of the poverty level that block group was not considered low income (greater than \$38,314) and assigned a score of 0. As the median household income values decreased the fuzzy score increased. So, the block groups that had a median household income between 100% and 150% (\$25,542 to \$38,314) were assigned a score of 33. Next, block groups between 50% and 100% (\$12,770 to \$25,542) of the poverty line were assigned a score of 66. Finally, if block groups were between 0% and 50% (less than \$12,770) of the poverty line it was assigned a score of 100.

The access to personal vehicles metric focused on addressing households that are without a vehicle. We selected these areas by using a boolean query. If 15% or more households in a block group did not have a personal vehicle then we scored those areas as 100 and all others as 0. The Race/Ethnicity metric focused on highlighting communities that have a high concentration of non-white populations. In our study area, block groups are assigned a score of 100 if the non-white population is 34% or greater of the total population. If the non-white population is between 17% and

34% the block group was assigned a score of 50. Finally, if the non-white population was below 17% the block group was assigned a score of 0.

Lastly, household density is broken down by low, medium, and high densities and scored accordingly, assigning high density a score of 100, medium density a score of 66, and low density a score of 33. All boolean queries are converted into a fuzzy scoring value, giving the areas of interest a score of one hundred and the other values a score of zero. These scores are then added together to generate a total score for each census block group and residential land use which results in a residential land use layer. Each score is thresholded using quantile breaks and five classifications, in order to split the quantity of values equally. The top twenty percentile is used as the area of focus for our analysis, which will favor the areas of highest value across all four variables (Figure 3).

Target Destinations

The next key concept is the destinations of the potential transit users of the BRT system. This includes areas of employment and retail opportunities. It is important that the BRT focuses on areas that are of higher density and usage, to provide the service to as many people as possible (VTA Transit 2007). Residential areas were scored according to their density, but with destinations, like commercial, industrial, and construction there is not an existing equivalent. We used land use information along with density of employment by zip code areas to estimate the density of employment and retail areas.

Areas of high population are better suited for bus rapid transit because it maximizes the amount of people served. The City of Madison's BRT Corridor Analysis gave us a guideline for the types of land use that should be served by the BRT (Schaefer and Gritzmacher, 18). The areas that were included are commercial, industrial, office, government buildings, and recreational areas, like parks and stadiums. While these locations are the best for overall BRT design, when focusing solely on providing the best service to transit dependent individuals some of these categories were deemed less important. The land uses which we focused on were for jobs that are typically held by lower income individuals. These jobs include general retail, commercial services, repair, construction, entertainment and industrial jobs such as manufacturing, and wholesale.

Employment density was calculated using the total number of employees in a zip code divided by that area of said zip code. The most recent data we were able to collect was from 2013, which is now half a decade old. Using this data applied a broad estimation of employment density. Thus the route could focus on reaching those areas, as they serve more people by area.

Target Destination Implementation

In order to create a working layer for target destinations, we first winnowed our jobs/activity land use layer, based on likely jobs that low income, transit dependent individuals would have. We created a layer that only contained commercial-retail, commercial-services, repair, construction, entertainment, and industrial land use classifications, which includes manufacturing and wholesale (Figure 2). We then

combined the employment density with the job/activity land use layer, which matched up the land use areas that are within a zip code. Next we applied the employment density values to each land use block. We then divided the values by the quantity of values using quantile breaks. We determined that the areas of highest significance are areas within the top 60 percentile (Figure 3). The reasoning behind this decision, was that the top 20 percentile and the top 40 percentile showed employment centered around the downtown area, and our focus is to serve the communities in the peripheries. In order to include these periphery areas, it was necessary to include the top 60 percentile.

Road Suitability

When determining optimal bus rapid transit routes, it is important to consider the suitability of the roads where the BRT will be driving. Articulated buses, which are suggested to be used in this system, have different requirements when it comes to lane width and turning radii. We applied constraints on the roads so that we could only use suitable roads when creating the BRT routes. While wait time at red lights was another concern in reliability of service, it was not taken into account which will be addressed later.

The dimensions of these articulated buses are typically a little over 8 feet wide and 60 feet long. The minimum lane width that is required to be able to implement a BRT lane is 10 feet, which we used to narrow down the available roads (American Public Transportation Association 2010, 21), (BRT Design Guidelines 2007, 26). The length of the bus requires a wider turning radius than a typical bus, which is more like

the turning radius of a semi-truck. A turning radius is 45 feet from the pivot point to the outermost part of the articulated bus, while the distance from the pivot point to the innermost part of the bus ends up being ~28ft (NACTO 2013). Subtracting these two distances gave us the total distance the bus will need on the actual road to make a right turn. Thus, we used 17 feet as the minimum width of the road that could be used for a BRT bus line.

Technology minimizes the need for concern on the reliability of BRT service. Waiting time at lights is one of the reason's buses currently run late, the City of Madison will be implementing intelligent transportation system (ITS) on all of the BRT buses to solve this problem. ITS is a way for the bus to communicate with traffic lights indicating when the bus is approaching so that red lights can change to green before it arrives (VTA Transit 2007, 50; MATPB "Regional ... Area" 2017, 5-31).

Road Suitability Implementation

In order to create a working layer for road suitability, we first needed a roads layer that contained the data necessary (i.e., road width and number of lanes). We used the calculation from NACTO to estimate turn radius, in terms of the road width necessary to make a right turn. Due to multiple data layers having different data that the others lacked, we combined data from the Wisconsin DOT, City of Madison, and Dan Seidensticker (of the MATPB), to create a complete road dataset. We then queried based on the minimum widths mentioned above, and created a complete roads layer that fit both criteria.

Results/Analysis

In order to determine where the BRT routes should connect we narrowed down the areas of interest as described in the the target origins and destinations sections of our implementation diagram (Figure 2). We broke up the origin and destination outputs using quantile breaks. Given that our focus is to serve the communities with the most transit dependent individuals we determined that only the areas with the top percentiles would be included in the final route decisions.

Ultimately we took the top 20 percentile for residential density (origin density) and the top 60 percentile for the employment density (destination density) as seen in Figure 3. We did not simply take the top 20 percentile from both the origin and destination output because the employment densities that were in the top 20 and even the top 40 percentile were too concentrated around downtown Madison. Considering that one of the primary goals of this project is to connect origins and destinations in both the center of the city and the periphery we deemed it necessary to expand that threshold to the top 60 percentile.

As a result of land use restrictions most of the remaining target origins and destinations were concentrated in clusters throughout the study area. Given this, we decided that rather than picking a specific point to connect in each cluster we would create polygons to represent those concentrated areas seen in Figure 3. Ultimately there were 38 total clusters where 23 represented residential origin areas and 15 represented employment destination areas.

In anticipation for comparison to the MATPB proposed routes we created two initial routes. We decided to connect the east and west peripheries through downtown and the north and south peripheries through downtown. Given the constricting nature of the physical geography of Madison the variability of route options are limited and must utilize the isthmus. The path of the primary and secondary routes are displayed in Figure 4 along with the origin and destination clusters that they connect. The primary route is the red route running from east to west, it connects along Washington Avenue in the east, before crossing around the square at the heart of downtown, down state street to University Avenue, and then loops back around near West Towne Mall. The secondary route is the green route which starts in the north along Sherman Avenue then connects to Washington Avenue, crossing over the square and feeding into Park Street/Fish Hatchery, eventually turning onto the Beltline Frontage Road. The measurement for service to a cluster was simple, if the route passes through or touches one of the polygons then that area was considered to be serviced. The primary and secondary routes connect 13 of 23 residential clusters and 8 of 15 employment clusters for a total of 21 connected clusters out of 38 possible clusters.

Considering that there were still a great number of clusters that did not have service from either our primary or secondary routes we determined that there was a need for more connectivity. Since BRT is meant to be rapid, more routes are preferable to fewer routes with convoluted connections. Thus, we concluded that the most viable option was to add more routes. The result of this decision is demonstrated in Figure 5. The yellow line, which is our tertiary line connects the residential clusters in Southwest

Madison to the east side of Madison via Monroe street. Our quaternary route, the blue line, connects the areas south and east of Lake Monona to the north and east sides of the city via Milwaukee Street. With these additional routes considered, 6 more residential clusters and 4 more employment clusters are served. In total with all four lines implemented the number of clusters served rises to 31 out of 38.

The routes proposed by the MATPB are similarly constricted by the geography of Madison, which made it so they followed a similar path, their first two lines running east to west and north to south (Figure 6). Since we wanted to have a one to one comparison between our routes and the MATPB routes, we decided to first compare our primary and secondary routes to theirs, excluding routes 3 and 4 from the comparison. Figure 7 shows the MATPB routes overlapping routes 1 and 2. There is not much deviance between the MATPB proposed routes and our own, with only slight variance at the fringes along the core areas both east-west and north-south. Our east to west line loops further north to capture more of the residential area cluster while the MATPB route loops further south to connect more of the employment cluster in that area. On the north-south lines the north end of the MATPB line loops to connect the cluster of residential areas, while on the south end, our route turns west to connect more residential areas.

We assessed the MATPB on the same criteria as the routes that we produced, if the line passed through or touched a cluster, that cluster was considered to have BRT service. Given the small variance between our proposed routes and the MATPB routes it comes as no surprise that the numbers of clusters served are similar as well. The two

MATPB routes connect 11 of 23 residential clusters and 9 of 15 employment clusters for a total of 20 out of 38 clusters connected.

Discussion

Between our primary and secondary routes and their primary and secondary routes, there was only one more target cluster that our route served, 21 for us and 20 for MATPB. There are a number of things to consider from this finding. First, there is the issue of Madison's geography. The city is essentially shaped like a bowtie, so all connections between cardinal directions must pass through the center. Furthermore, the grid system of the roads does not stay consistent the further from the isthmus one goes. This means that there are fewer roads that fit the criteria of our road restrictions as we moved out from downtown. Since these are two relatively prohibitive restrictions, the options for routes are limited.

Second, as we determined prior to our comparative analysis to the MATPB, there is no reasonable way to connect all of the target clusters with just two routes. Thus there would be a need for more routes to achieve higher levels of equity. Our route 3 and 4 solutions to this issue are not exactly ideal routes. For example route 3 only incorporates one more target cluster outside of the reach of routes 1 and 2, albeit while also serving other residential neighborhoods (Figure 5). As for route 4, the route is not ideal for BRT because it incorporates an inordinate amount of turning, simply as an attempt to connect as many target clusters as possible. Even with these additions there are still 7 clusters that we were unable to connect.

Furthermore, this analysis is flawed for how extensive the geographies of the cluster areas are. Just because a proposed BRT line touches or intersects one of those polygons does not mean that the line is within reasonable walking distance for all the people living in that cluster. Ideally, the connections would be made while also considering walking distance. In addition, the target clusters would cover a much smaller spatial extent to reduce the ambiguity of this analysis.

Ultimately, the MATPB proposed primary BRT route is virtually as equitable as the primary routes that we produced. That being said, connecting only 20 or 21 target clusters out of 38, means that there is more that needs to be considered. There are standard bus routes that service the areas which we targeted with our yellow and blue lines. Realistically, given the road restrictions, and physical geography, those areas just may not be viable for a BRT line. Perhaps the best solution to this is to incorporate those missed target clusters into the BRT plan with standard bus connections to stops along the BRT routes.

Conclusion

With Madison's problem of overcapacity with the current bus system in place, a bus rapid transit system looks to be the most feasible and affordable option in comparison to the alternatives. Our project goal was to create bus rapid transit corridors that are designed for equity. We wanted the corridors to serve communities that were low income, without a personal vehicle, non-white, and living in high density housing. We also wanted to serve areas of high employment density that transit dependent people would most likely commute to. Our primary and secondary routes allowed us to serve these communities to a certain extent. Comparing our routes to the MATPB's proposed corridors it was clear that each design virtually met the same equity measures. Both serve nearly the same amount of origin and destination clusters. However, many origin and destination clusters were left unserved, in both cases, when using only the East-West and North-South corridors. The addition of our supplementary corridors served more origins and destinations clusters. Although, these routes would not make for practical BRT corridors, either because they are redundant, inefficient, or both. Given our concern about serving transit dependent individuals, the best course of action may be to incorporate the standard bus routes in those areas as feeders to the primary BRT service.

Future Research

More research should be done to insure that the BRT takes everything into account before it is implemented. Our main struggle was the lack of detailed data which limited the scope of information when it came to determining the origins and destinations of transit dependent people. Demographic and employment density data were both collected at a large spatial extent which is not precise enough. By using an aggregated spatial extent we are not able to pinpoint the exact location of transit dependent populations. In other words we don't know if we have captured the full extent of our target population. The scale which should be used for both origin demographics and employment density information would be at a block level. Having detailed demographic information would allow us to really concentrate where exactly the BRT route needed to go. Employment density information would also benefit from having more detailed data. Going from zip code level to block level, would allow for more detailed information, which could drastically impact our results. From the road data, we had a lot of detailed information and used what we needed, but there were some areas where we just lacked the ability to apply that information. Characteristics like speed and traffic conditions could be added into our analysis, which would greatly improve the optimal BRT routes that we designed.

Layers that were not included in our study but should be, in order to cover as many people as possible, would be park and ride areas and transfer points. A lot of people use transfer points to connect to different buses to help them get to their destination. Park and ride does the same thing, but lowering the number of cars that

are on the streets and having more people use the BRT overall. Connecting the BRT to these different areas is important, but the same mentality should be placed onto the impact the BRT will have on the people living along these new corridors. When any city adds in a new transit line, it results in raising land value along the corridor. The rise in land value creates displacement, which is seen more frequently in communities that need the transit service the most, i.e. transit dependent communities. The City of Madison should take these impacts into account by enacting a policy to help these people from being displaced at all. Overall more detailed research and time should be taken into account to be able to really target the transit dependent communities and place bus stops where it can serve as many people as possible.

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Appendices

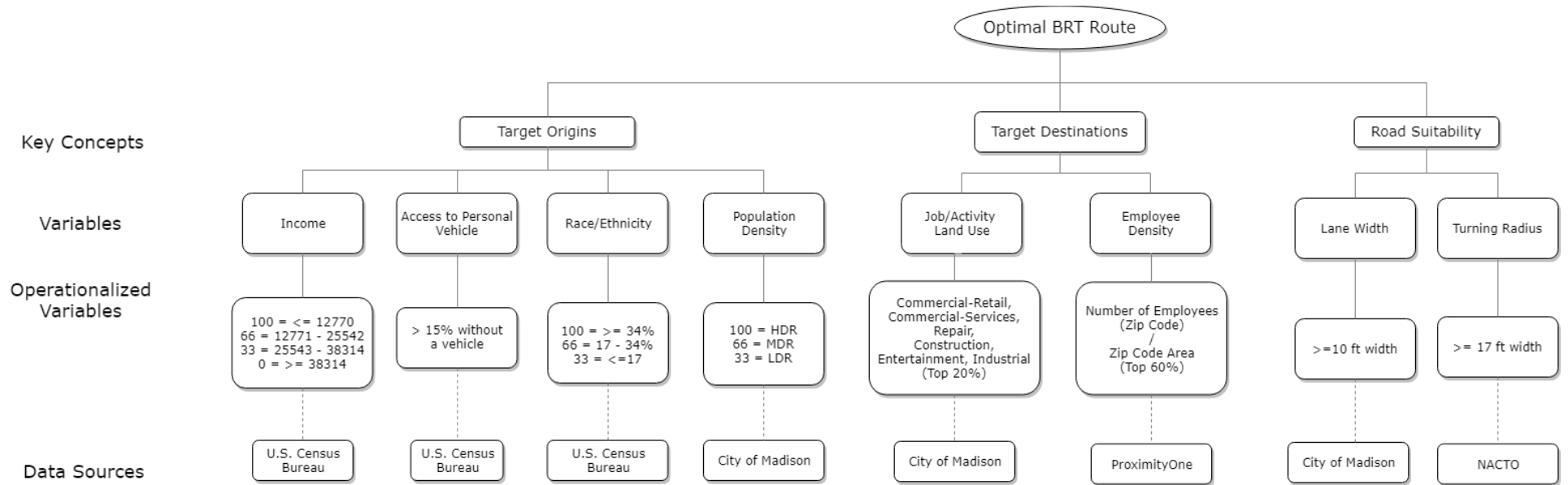


Figure 1. *The conceptualization diagram highlights our key concepts and the primary variables that constitute those concepts*

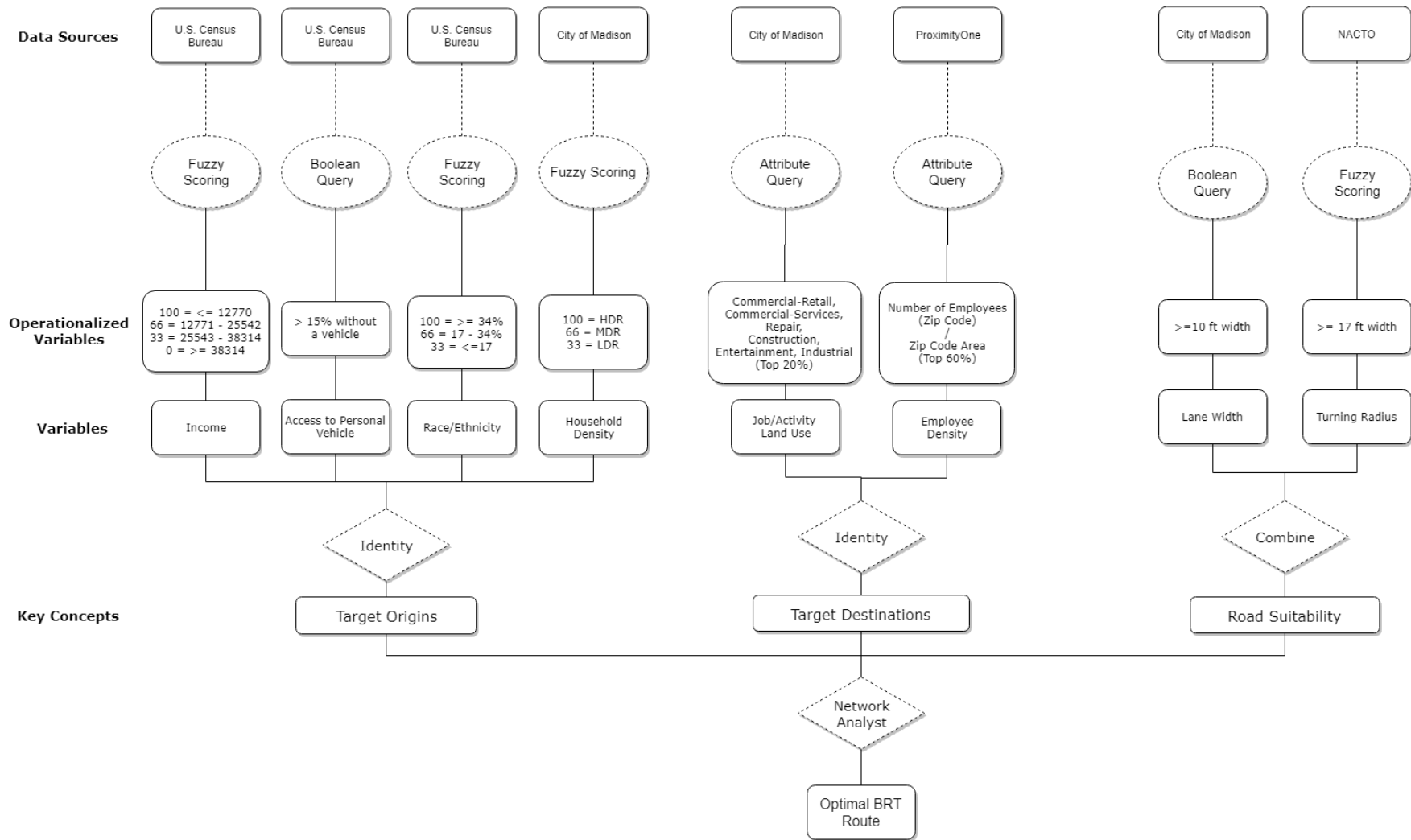


Figure 2. *The Implementation diagram highlights the GIS operations applied to the operationalized variables to reach our final output.*

Weighted Origins & Destinations

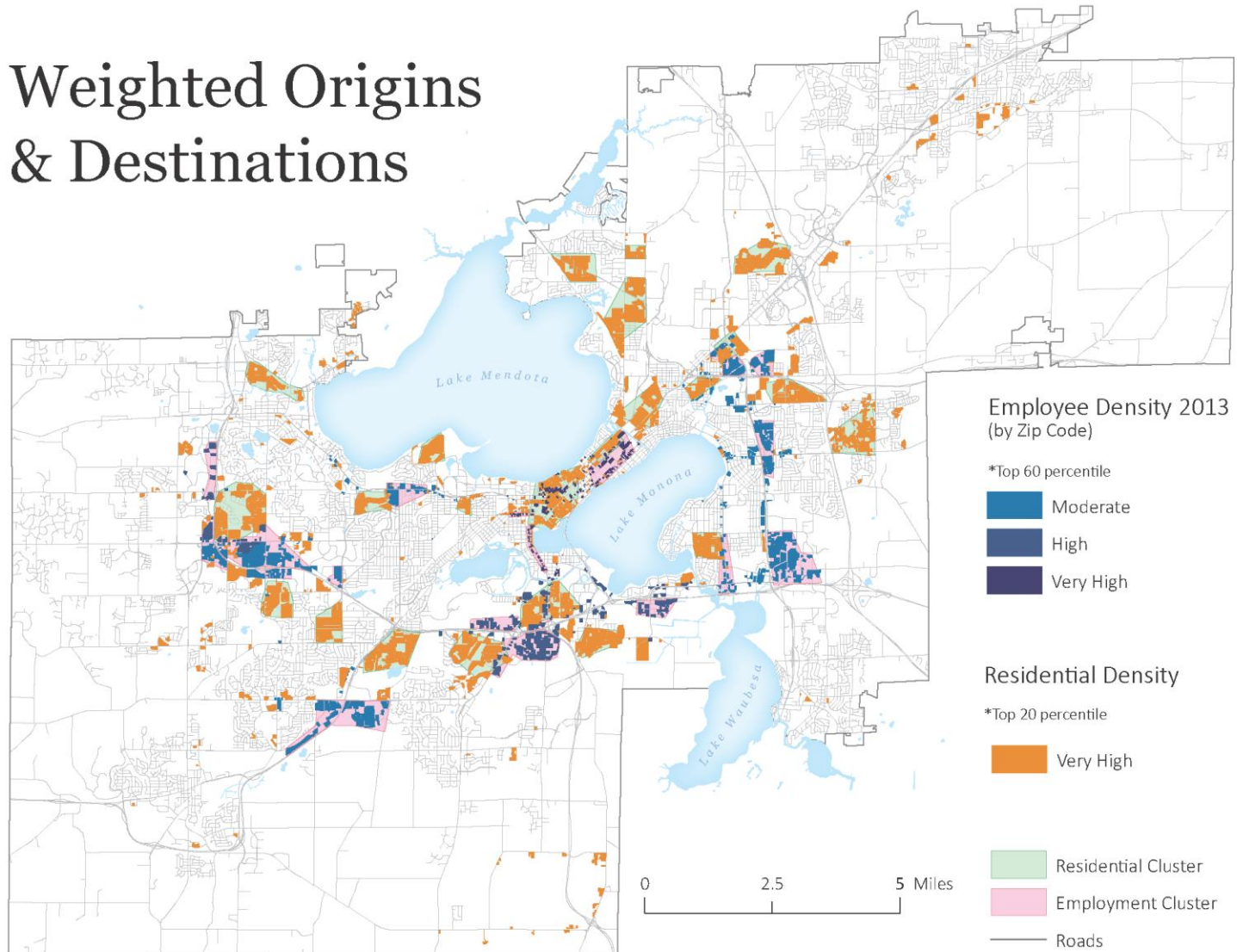


Figure 3. This map visualizes the origins and destinations outputs conceived in our diagrams

Primary & Secondary Routes

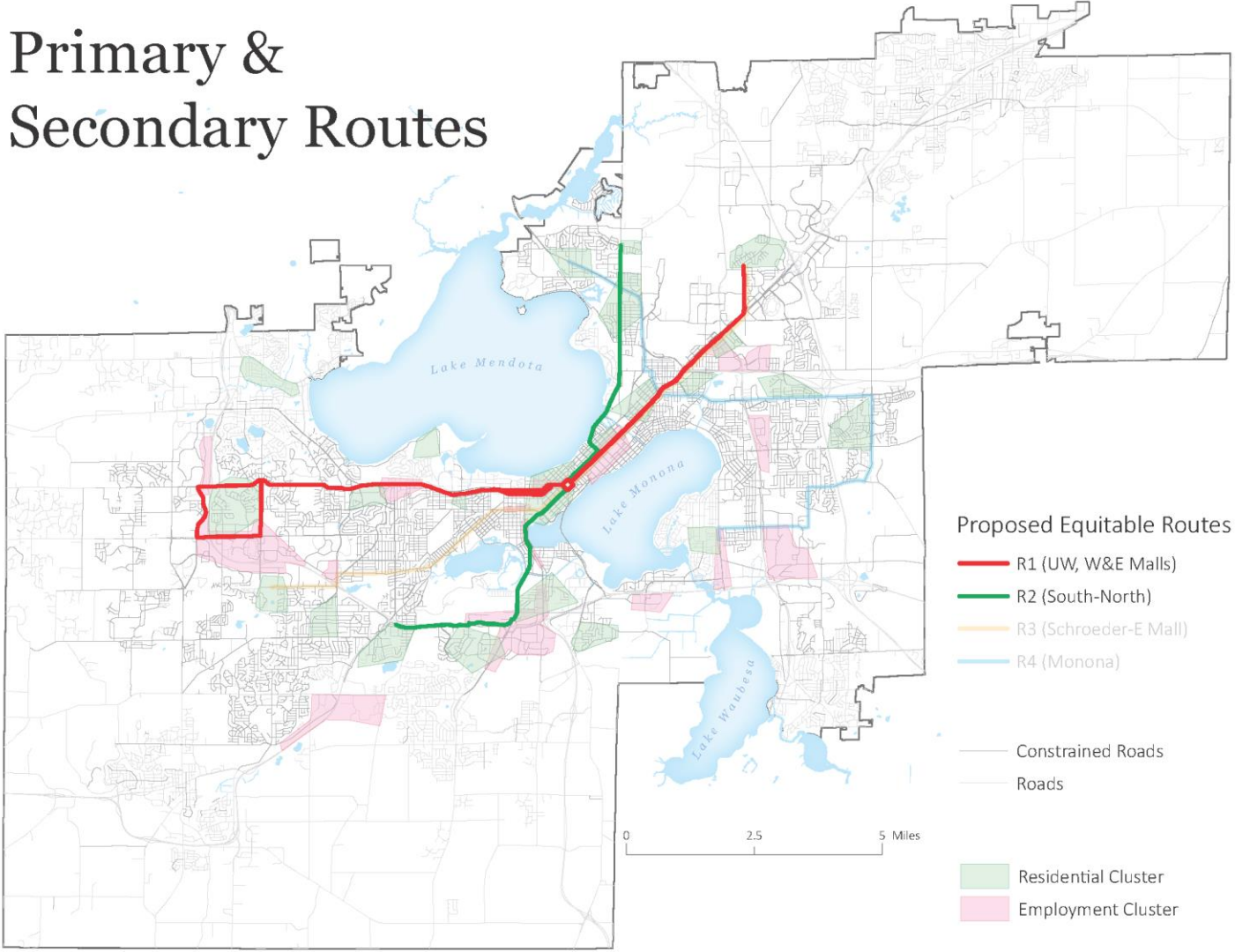


Figure 4. The resulting output for the proposed primary and secondary equitable routes

Equitable BRT Routes Madison, WI

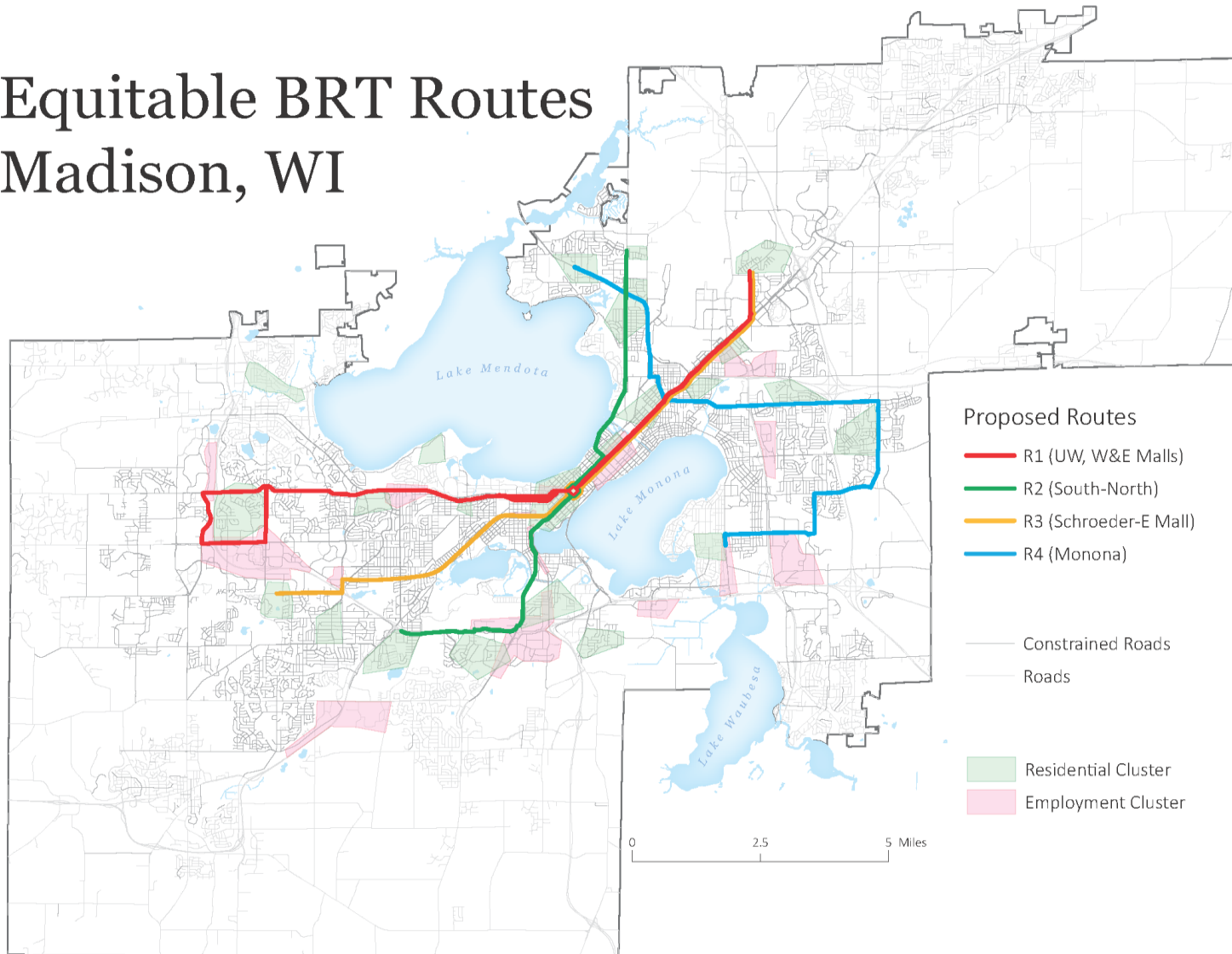


Figure 5. Output of all proposed equitable routes including supplementary routes 3 and 4

MATPB Proposed BRT Routes

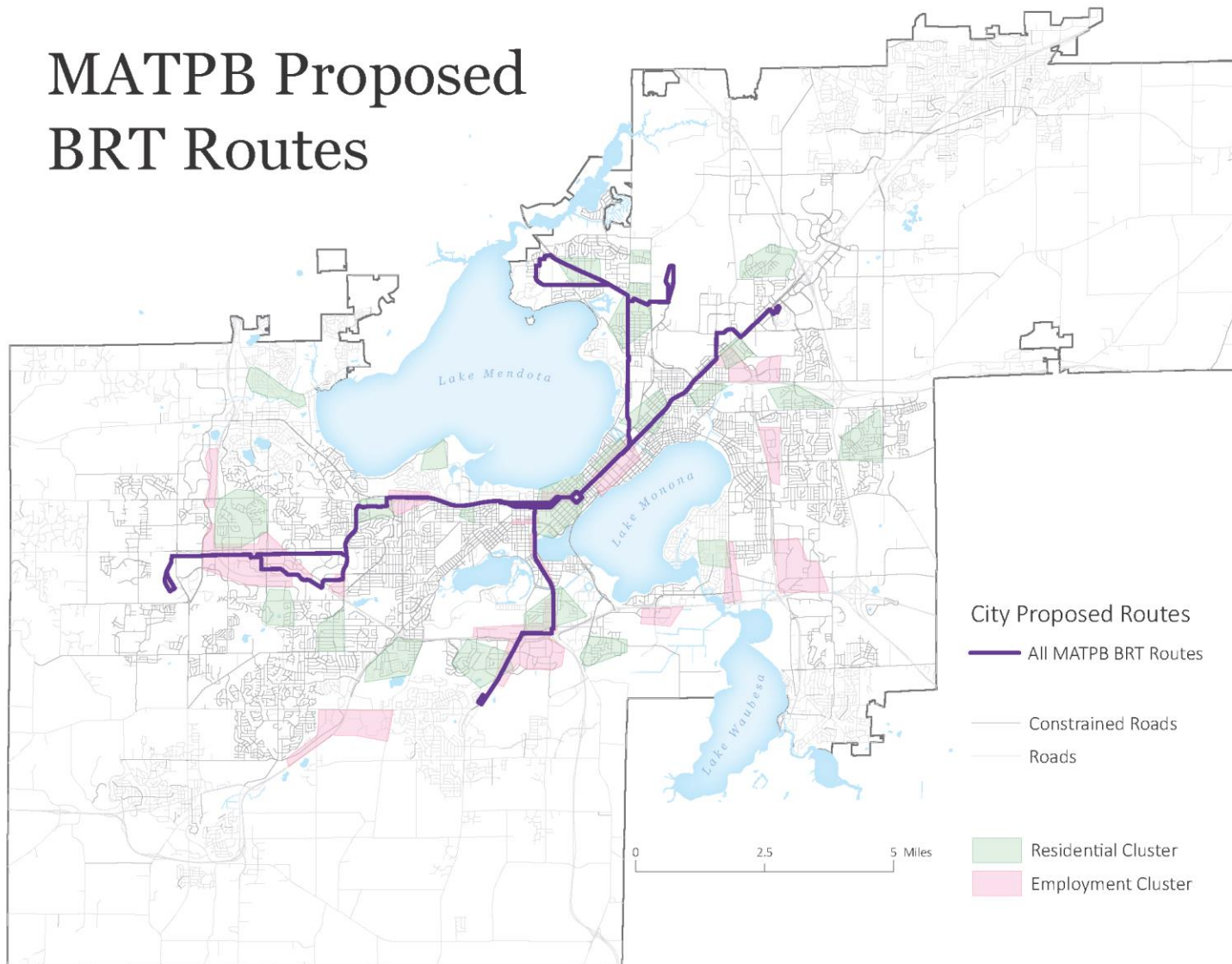


Figure 6. Visualization of the routes proposed by the MATPB overlaid with basemap of origin and destination clusters

Primary & Secondary Routes Comparison

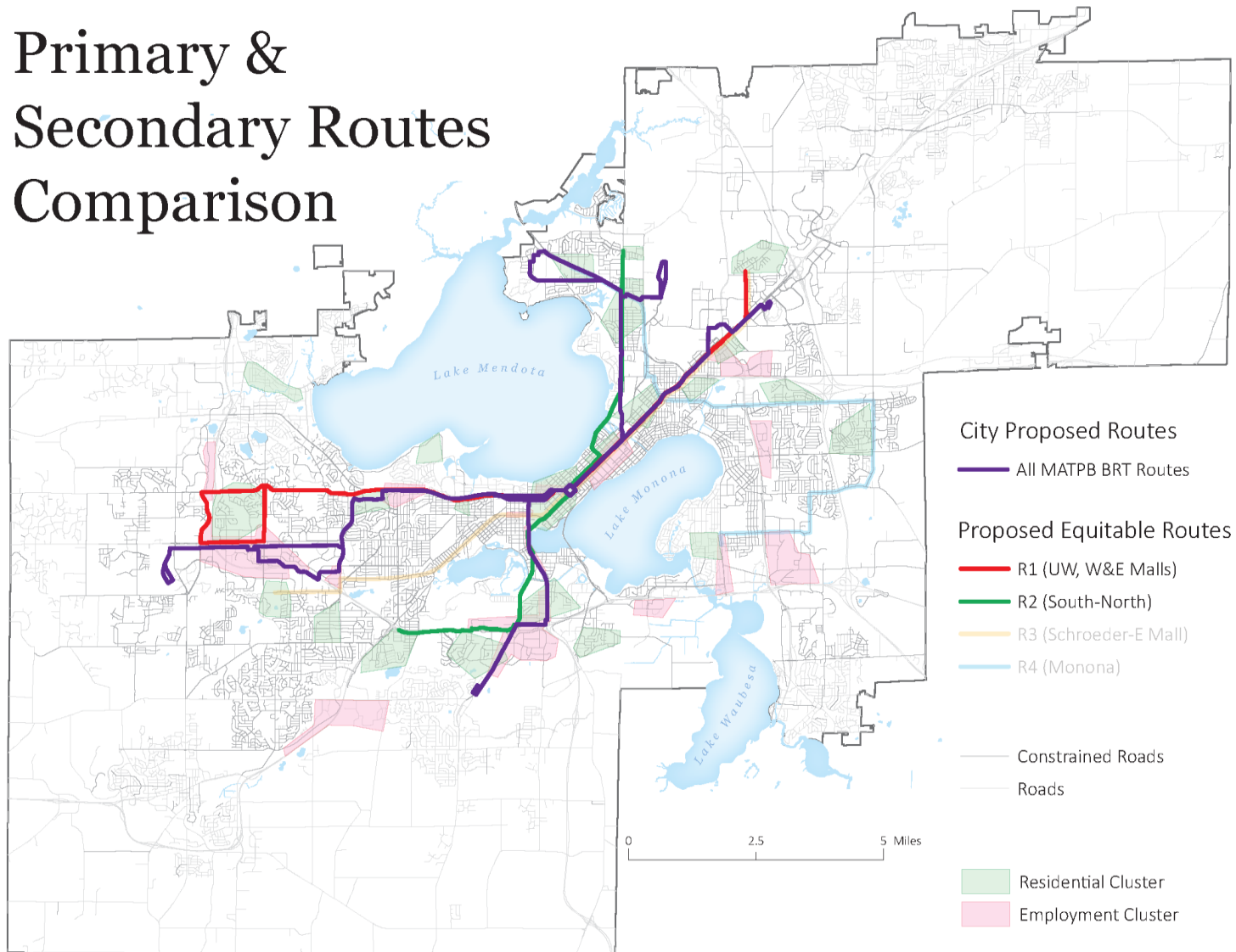


Figure 7. Comparative overlay of MATPB and our Primary and Secondary routes