

Optimizing Bus Routes in Detroit, Michigan:

**An analysis of relevant destinations, origins, and the routes
connecting them.**

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1.0 Capstone Statement

Due to a high population of residents without personal cars and the limited extent of bus routes in Detroit, Michigan, the city could benefit significantly from redesigned bus routes. We are going to perform a route and site suitability analysis in order to establish new bus routes in Detroit. We want to create a data layer representing new bus routes that form a more extensive and efficient network of public transportation services than currently exists. The design of new bus routes for Detroit will be guided by an emphasis on the importance of access to critical resources, like business districts, food, healthcare, and schools, for people of all socioeconomic status'.

2.0 Introduction and Background

The city of Detroit, Michigan lies on the eastern side of the Detroit River, opposite the border of Canada. The city has a long history as an automotive giant, and was home to “the big three” in automotive companies: General Motors, Ford, and Chrysler, (Ryan 2013, 1) earning it the nickname “The Motor City.” Unfortunately, since the automotive hardships of the 1970’s, Detroit has been in a downward spiral; a spiral that was only accelerated during the nationwide recession of 2007. The recession hit Detroit hard, exasperating an already troubled city; it left the landscape of Detroit pockmarked by vacant lots and crumbling abandoned buildings (Ryan 2013, 2). The city’s job market has continued to decline since the late seventies, accompanied by the city’s population, ridership on the city’s transportation system, and an inverse rise in poverty, vacancies, and inequality (Ryan 2013, 4-6). Detroit hit its rock bottom in 2013 when its \$20 billion worth of unpaid bills spurred the largest municipal bankruptcy in the history of the United States; one in three Detroiters now live in poverty (Detroit Population 2017). The city’s

transportation system is ineffective and that needs to be improved if Detroit is to effectively combat its issues. The city's ridership is down 90% since its peak in the 1940's (Grabar 2016), a major issue considering that Detroit's percentage of carless households, about 25%, ranks eighth highest nationally (Grabar 2016). Even more troubling is the apparent lack of concern taken by the city; Detroit spends about \$69 per capita per year on transit (Grabar 2016), a figure that ranks only above the cities of Phoenix and Tampa nationally (Henderson 2015). A major issue with Detroit's transportation is its inability to connect the city to the suburbs, where many low income jobs that employ Detroiters are located. This is a major concern considering that about three in five Detroiters work outside the city (Grabar 2016) and therefore cannot access their jobs with the city's transit system. Jobs within the city itself are perhaps even more inaccessible to low income Detroiters, despite the proximity. Detroit jobs are often higher-wage jobs that typically require a college education, an issue that is reflected by the three quarters of the jobs within Detroit that are occupied by people living in the suburbs (Grabar 2016). The resulting landscape of job sprawl is similar to what might be seen in impoverished rural Appalachia (Henderson 2015); 77% of jobs in the metro area are more than ten miles, and as far as thirty five miles, from the city's central business district (Henderson 2015). The western communities are particularly job-rich, however public transit does not reach these suburbs (Henderson 2015), leaving those looking for employment here to find their own ways to reach potential jobs.

The Detroit metro area is primarily served by two main transit systems; the Detroit Department of Transportation which primarily services the city, and the Suburban Mobility Authority for Regional Transportation, or SMART, which operates primarily between the suburbs. The issue arises in the fundamental split between the two systems; both are separate in

their management and funding. Communities serviced by the suburban-funded SMART have the ability to opt-out of the bus service; fifty-one of which did, in addition to the City of Detroit itself (Lawrence 2015). SMART is the only system in the country that allows opt outs (Lawrence 2015), and the result is a suburban landscaped peppered with large gaps in bus service, and an inability to transport users within the city. Here in lies the problem; a massive disconnect exists between one inefficient system that operates only within city limits, and another inefficient system that operates only in selected suburbs. For many years there have been attempts to merge the systems, and in 2012, after twenty four attempts, the Regional Transit Authority (RTA) was finally created (Kaffer 2015). While this is a definite step in the right direction, the RTA does not yet have the ability, funding, nor organization to merge the systems, and has instead focused on the creation of a bus-rapid transit system which unfortunately would be in addition rather than a replacement to the existing systems (Kaffer 2015).

Underneath all the complexities and faults of the Detroit metro transit systems lies another issue: race. One of the most racially segregated cities in America, Detroit's dwindling population registered at 677,116 in 2016, 82.7% of whom are black (Detroit Population 2017). However, when looking at the entire Detroit Metro area, which encompasses 4,297,617 people, the racial composition swings to 67% white (Census Reporter 2016). The three peripheral counties focused on in our research, Wayne, Oakland, and Macomb counties, record white populations of 54.6%, 76%, and 81.9%, respectively (U.S. Census Bureau 2016). This shows a clear discrepancy between race and location, and enforces our stance that transportation systems must be improved equitably and regionally.

This report will encompass the conceptualization of new bus routes in Detroit, then will move into a discussion about the determination of important destinations, demographics, and road suitability necessary for equitable implementation before finally concluding with a section concerning the overall network design and its limitations.

3.0 Conceptualization

The goal of this project is to design new bus routes for Detroit, Michigan, that will better serve the city's residents. This will be accomplished by determining where important destinations for public buses are located, where important journey origins are located using demographic information, and which roads are most suitable to be traversed by bus in between origins and destinations. The conceptualization of these three key concepts is explored in this section of the paper. The conceptualization of this project is summarized in Figure 1.

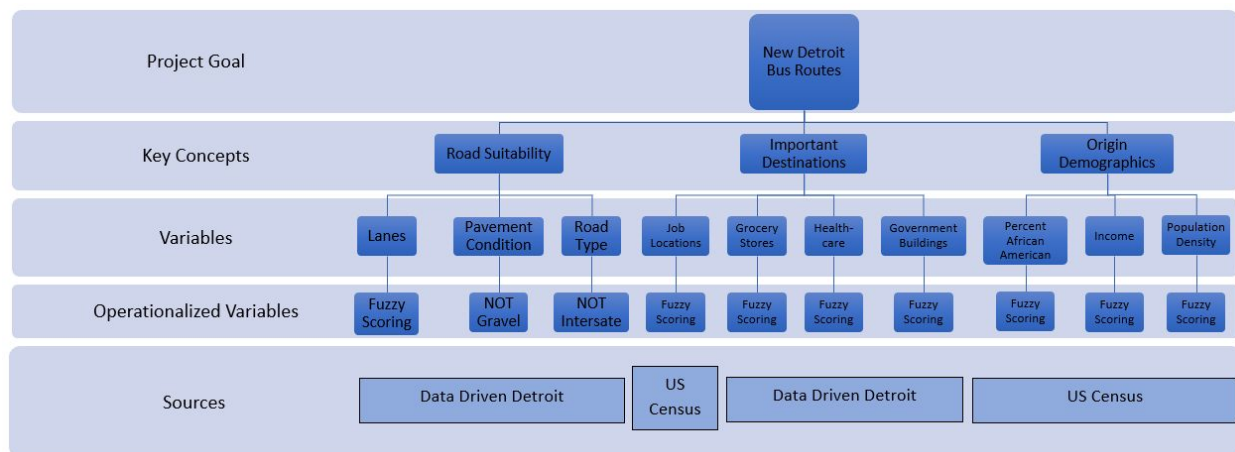


Figure 1. Conceptualization diagram representing the segmentation of the project into three key concepts and the variables that comprise each of these concepts.

3.1 Important Destinations

Public transportation serves as an inexpensive option to move people from place to place in a city. Public transportation systems cannot be effective if they do not take people from their homes to their destinations. Detroit's public transit system needs help because it often fails to bring people to the destinations to which they most need access: work and grocery stores. In order to determine which regions of Detroit and its surrounding area are most in need of public transportation it is necessary to determine how important access to different commodities is, relative to one another. In this study, four different location types are being used to determine areas that need bus access. The different locations being emphasized as important resources include hospitals and healthcare providers, government buildings, food and grocery stores, and popular centers of employment. These location types are all considered critical resources to which every human should have equal access. Detroit has a history of under-providing public transportation to both jobs and grocery stores (Zenk et al 2005)(Turner 1997). Even though there is nothing to suggest that hospitals and government buildings are not easily accessible, it is important that in attempting to provide better access to underserved resources, other destinations are not forgotten and left underserved themselves with the new design.

Ensuring that bus routes service important destinations will be accomplished by performing a weighted overlay of the four different variables used to define which locations in Detroit are important. Before the weighted overlay is executed, the raster layers on which the overlay will be based need to be created. The original data for the hospital/healthcare, grocery store, and government building layer will all be represented by point data. The grocery and hospital/healthcare layers contain all the points necessary without any editing because Data

Driven Detroit offers datasets representing hospitals and grocery stores in Detroit. There is no point layer that represents areas with high jobs concentrations or a point layer containing all relevant government buildings. These two layers will need to be created using a combination of digitization and the querying information from related datasets that already exist.

The data representing popular places of employment is initially represented in a vector layer made up of polygons. Each polygon is a census tract with an attribute representing jobs per square mile. When broken into five classes using equal breaks, only the class representing the census tracts with the highest concentrations of jobs will be used to determine where most people travel to work. This is the top 20% of census tracts based on job concentration. Next, a point layer containing the centroids of these areas will be created. These are the points that will be used to create the raster representing distance to areas with high employment concentrations.

The point layer representing government buildings will contain polling places, city halls, courthouses, and DMVs. These are all places that every citizen should be able to access without their own personal car. A point layer representing polling places already exists, but every other point must be digitized based on their coordinates in Google Maps. Unfortunately, it was not possible to find these locations within an existing geospatial dataset. Once the polling locations in the already existing layer and every other government building is digitized into the same file, this point layer is ready for the next step of the analysis.

Each point layer representing a specific type of commodity now needs to be turned into a raster. A proximity analysis will be performed so that the pixel values in the raster images for each layer will represent the distance from the nearest point in the point layer to any given

pixel's location. Since the pixel value is distance for each of these four raster layers, no further scoring needs to be done in order to prepare them for the weighted overlay.

This project's goal is to redesign Detroit's bus routes because the current bus system does such a poor job of serving the needs of many people in Detroit. It is important to focus both on improving public transit where it is lacking and maintaining its strengths. For this reason, the relative weights of each important location layer will not vary by much. Because so much evidence suggests that many Detroit residents struggle to commute to their place of work this variable will be weighted the heaviest at 32% (Henderson 2015). The evidence also suggests that African Americans in Detroit are disproportionately far from grocery stores, so this variable will be weighted second highest at 27% (Zenk 2005). Healthcare will be the third highest ranked variable because there are fewer healthcare facilities than there are points in any other destination layer (Rubio 2015). This means that people, on average, will need to travel further to reach healthcare, it was also assumed that healthcare is less frequently visited than employment centers and grocery stores, and in emergency situations people would travel via ambulance rather than public transit. Its weight is 23%. Finally, the government buildings layer will be allocated the lowest weight because they are so densely distributed throughout Detroit (IET 2017). Access to these locations is still important for Detroit's residents, but locations like polling places are often already within walking distance of people's homes. Similarly, public buildings are visited on a much less frequent basis than the other three variables. Its weight is 18%. Figure 2 summarizes the weights assigned to each variable for the weighted overlay.

Employment Centers	35%
Grocery Stores	24%
Hospitals	23%
Government Buildings	18%

Figure 2. Relevant destination weighted overlay distribution summary

Once the weighted overlay is complete the resulting raster layer can be used to select destination points for bus routes in Detroit. While destinations are important, bus routes stopping near the density analysis clusters within the weighted overlay region only help if they are bringing people from the origins whose residents need access to these resources. In the next section, variables including population density, racial demographics, and median household income will be used to determine the locations from which people will often begin their bus journey's.

3.2 Origin Demographics

While jobs, hospitals, grocery stores, and government buildings are all important destinations for the people of Detroit, most of these people will be traveling to these locations from their homes. To design effective bus routes, it is important to understand where people in Detroit live, in addition to which demographics most need public transit to travel to their destinations. To determine where people are coming from this study will use three different variables: population density, median household income, and race.

The first variable, population density will be used to determine where all people live. Using data from the US Census Bureau at the census block group level, each block group will be

represented as a function of the people per square mile that reside there. This vector representation of block groups in Detroit will then be converted into a raster file. The pixel values in the raster file will be scored from one to five; five represents block groups with the highest 20% of population density, while 1 represents block groups with the lowest 20% population density.

Next, the distribution of different races in Detroit will be examined. Detroit has a disproportionately high population of people of color below the poverty line, and poorer people are more likely to need public transportation – especially in Detroit, where the percent of people that own cars is one of the lowest in the entire United States (Detroit Population 2017)(Graber 2016). So, this layer will be scored based on the percentage of the population in the census block group that is black. The census blocks with the top 20% of the residents that are African American will receive a score of 5 and the bottom 20% will get a 1.

The last variable to consider when determining important origin locations is median household income. Detroit, as a city, has a very low median household income of \$26,249 (*U.S. Census Bureau QuickFacts: Detroit city, Michigan*). As it was mentioned earlier, Detroit also has a very low percentage of residents that own personal vehicles (Graber 2016). Despite not having cars, low income residents still require transportation, and the best option is often public transportation. Median income by census block group will be scored into 5 different classes, with the top 20% at a 1 and the bottom 20% at 5. The bottom 20% receive a score of 5 because these neighborhoods are usually more in need of public transportation than wealthier sections of Detroit.

Once a scored raster is created for each demographic variable, a weighted overlay will be performed. The areas with the highest scores within the weighted overlay represent origin locations that are most in need of public transportation access. For this overlay, the population density variable will be assigned a 36% weight while both percent African American and median household income will be given a 32% weight. The population density is allowed more weight than the other two variables because it is important to ensure that every neighborhood have access to bus routes, not only neighborhoods composed primarily of marginalized groups. It should be noted that this project, while attempting to offer equitable public transit for all demographics, focuses specifically on Detroit's African American population. The justification for this focus lies in the demographics of Detroit; the city is roughly 83% African American and roughly 14% white alone, (*U.S. Census Bureau Quickfacts: Detroit city, Michigan*) so while it is important to offer equal access to all other minorities, in Detroit their population is statistically negligible, and therefore their inclusion could alter the focus of the project without properly representing the city. Figure 3 summarizes the weighted overlay weight distribution. Once the overlay is complete, the resulting layer and its 'hot spots' can be used to determine from where bus users need to get on a bus in to travel through the city.

Population Density	36%
Percent African American	32%
Median Household Income	32%

Figure 3. Origin Demographic weighted overlay distribution summary

3.3 Determine Road Suitability

For the purpose of designing the most effective bus routes through a relatively large geographic area, attention had to be paid to the type of roads that will make up each new bus route. This study looks for roads that meet specific criteria for bus travel based on their condition, type, and size. Each of those variables was classified into their own respective scoring schema relative to the respective needs of the city and the goals of the proposed bus system. From the vector layer of roads and their attributes, a field was added which aggregates the suitability of each road variable, and then the road layer was used in the network design to determine the most suitable path between origin and destination points.

Condition is obviously important because it would be detrimental to the road network and entire transportation infrastructure of metro and suburban Detroit to build most of the bus network on degraded roads. The analysis did not entirely exclude degraded roads as this would be overly exclusive to the actual road network that might be used. Pavement surfaces were scored by road surveying data based on the PASER (Pavement Surface Evaluation and Rating) scale of 1-10, 10 being the most pristine pavement surface (Transportation Information Center 2002). Figure 4 below shows the distribution of road conditions in the tri county study area classified into 3 Ranges of the PASER scale: Poor, fair and good. The map symbolizes poor quality pavement in red (PASER 1-4), fair surfaces in yellow (PASER 5-7), and good in green (PASER 8-10). This data clearly displays how many road surfaces in the metro area and surrounding suburbs of Wayne, Macomb and Oakland County are only in fair or poor condition, which is why it makes sense to use fuzzy scoring so that roads in poor or fair condition are not excluded from the analysis if they need to be used to complete a potential route. The scoring

schema for a rasterized version of this layer still puts appropriate priority in developing routes on good quality surfaces. Interstates were not included in the analysis, so the pavement quality analysis was only performed on surface roads.

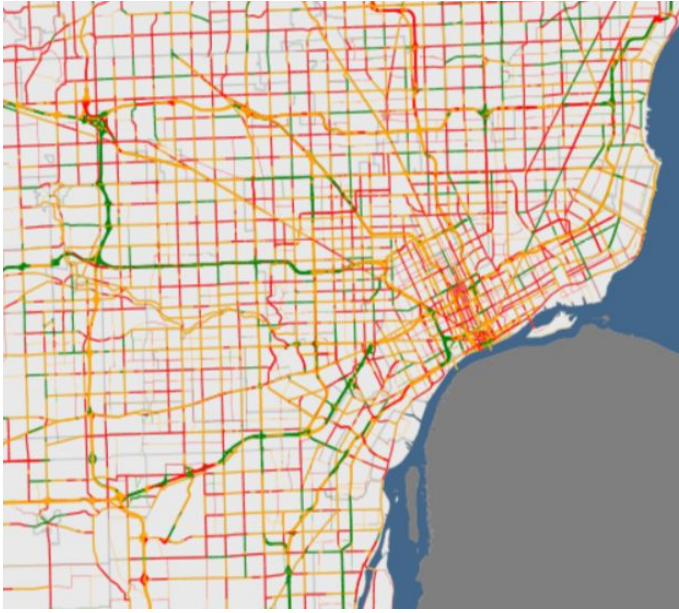


Figure 4. Source: SEMCOG Pavement Condition

Interstates were not included in the analysis because they could create a major barrier for bus riders to accessing the targeted ground resources and this proposed bus network does not necessarily aim to be a Bus Rapid Transit (BRT) system. BRT systems generally attempt to connect key areas using a direct bus path and in doing so minimize the stops and travel time between them. This is typically done with a dedicated bus lane making all phases of bus ridership more efficient (ITDP 2018). A dedicated bus lane is out of the scope of this project, although a separate component of the road suitability analysis takes into effect the possibility for future dedication of bus only lanes when possible. Using interstates for bus travel in Detroit could create a major barrier for bus riders to accessing the targeted ground resources.

In addition to excluding interstates, it will also be necessary to consider the classification of the roads included in the suitability analysis. To include this information, the National Functional Classification (NFC) will be used for each road surface. The NFC scale classifies road segments into interstates, major and minor arterial, major and minor collector, or local roads (MDOT 2014, 9). The scale is meant to signify high mobility in the low values (interstates, arterial) and high property access in the high values (local). Arterial and collector roads will be considered as the most suitable while local roads will be considered less suitable and interstates will be completely excluded. The majority of our bus routes should not run through residential areas and the collector roads are meant to provide access to these areas, so this weight is proportional to appropriate access for our bus routes.

The last component of the route suitability analysis takes into account the number of lanes on each prospective road. Similar to the road condition analysis, this information was given a unique scoring schema from 1 through 7 lanes, with 3-5 considered the most suitable for bus travel. By only selecting surface streets, the number of lanes gives an analogue of surface activity as well as highest areas of flow. 3-5 lanes were considered to have the best traffic flow and provide the most promise for a potential BRT addition in the future of this transportation plan. The National Association of City Transportation Officials cites dedicated transit lanes as one of the most effective ways to make a bus transit system run most efficiently, along with features such as appropriate base signal timing and operational traffic improvements (Urban Street Design Guide). More lanes per road provides the opportunity to dedicate one of them for buses only as well as provides more room for the bus to stop without heavily disrupting traffic. The design and implementation of bus only lanes is outside of the scope of this project,

but within the general goals of maximizing accessibility and ridership for Detroit residents it makes sense to design in room for growth with tested and proven ways to maximize productivity. Road segments with fewer lanes are lower flow intended mainly for property access and were scored relatively lower because of this. Roads with a high number of lanes are likely heavily trafficked roads that would make it difficult for a bus to stop, so they were also weighed relatively lower. Similar to the rationale for scaling pavement condition, a progressive scale of lane numbers weighed the most ideal roads higher without excluding single lane roads in the event that they needed to be utilized to complete bus routes.

For the final analysis and output, it was necessary to score number of lanes, NFC classification, and pavement condition together to get an aggregate value for road suitability. In the interest of incorporating elements of a BRT design, number of lanes on each road and NFC classification were scored slightly higher than pavement condition. Pavement condition is still crucial to the selection of roads for new routes, so it was important that weight for both remained significant. The variables were aggregated into a single field for suitability, and this field was used in the final network of bus routes to create a network dataset on which our new routes will be generated.

Number of Lanes	35%
NFC Classification	35%
Pavement Condition	30%

Figure 5. Scoring of Road Suitability Variables

3.4 Network Design

The end bus network design involved the utilization of multiple weighted raster layers which each account for different variables composing the key concepts. The Network Analyst toolset in ArcGIS was used to perform the final output of bus routes. This involved the creation of a network dataset from our roads and suitability score. This dataset served as the possible surfaces for the routes to travel on. The Network Analyst considers the potential routes to travel on and their impedances (road suitability), and uses origin and destination points to create routes which provide access to those points in the most efficient way according to the impedances of the road network. The algorithm produced outputs that are not realistically suitable for bus routes, so they needed to be manually altered in order to be realistically implemented.

4.0 Implementation

There were several components of the implementation process that remained consistent across the entire process. Namely the data projection and raster pixel size. UTM Zone 17N in the NAD 1983 Geographic Coordinate System was agreed upon as the projection. All produced rasters were created with a pixel size of five. Due to the chosen projection, this means that each the side of each pixel is five meters long.

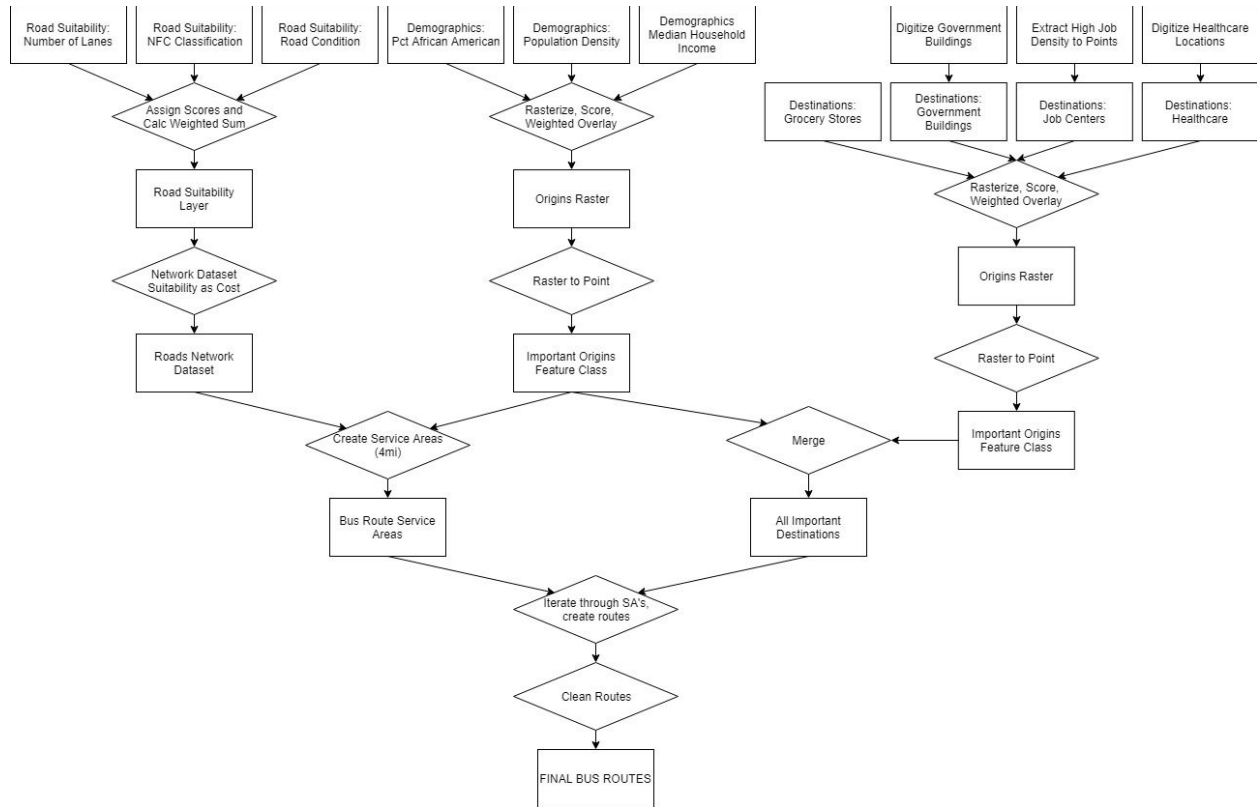


Figure 6. Implementation diagram detailing the data analysis and processing steps from the start of the project to final output.

4.1 Important Destinations

The four variables guiding the determination of important destinations to be included along bus routes included healthcare, government buildings, grocery stores, and places of employment.

To begin, healthcare includes all hospitals within the Detroit city limits and all free clinics inside the city. A data layer representing hospitals was available via Data Driven Detroit, but the free clinics were digitized according to their address. The addresses were collected from FreeClinics.com. Once every relevant healthcare point had been consolidated into a single dataset, the Euclidean Distance tool was used to generate a raster where the processing extent

was defined as all of the city of Detroit. The pixel values in the resulting raster represent the distance, in meters, to the nearest healthcare point.

The next variable taken into consideration was government buildings. Included in variable are police stations, city halls, and courts within the Detroit city limits. No data layer representing the locations of these points exists. In order to create these points, the latitude and longitude from their locations in Google Maps were used as X and Y values in ArcGIS. Then, to maintain a consistent projection, the data layer was projected into UTM Zone 17N. Finally, the Euclidean Distance tool was used again to create a raster representing the distance to the nearest building for every five by five meter point within Detroit.

The third variable considered was grocery stores. Points representing every grocery store in Detroit was available via Data Driven Detroit. The points were projected into UTM Zone 17N, and the Euclidean Distance was used on the points across the entire city of Detroit.

The fourth and final variable considered an important category of destinations was job centers. Job data was collected at the Census Block level from the LEHD Origin-Destination Employment Statistics (LODES) database. The original dataset represented employment data as Census Block polygons. Census Blocks were determined to be relevant job destinations if they had an employment density of at least 75 employees per acre and a minimum of 75 employees working within the block total. The 75 employee minimum was used in order to exclude small census block that may have had a high density, but low number of actual employees. All selected Census Blocks were extracted, and their centroids were used as the input for the Euclidean Distance tool. The tool was run twice, once with the processing extent set at Detroit, and once for the entire study area: Wayne, Macomb, and Oakland counties.

By this point, four new rasters had been created. The next step was to apply scores to each of the rasters and overlay each of the four rasters using the Weighted Sum tool. Figure 2 describes the weights that were assigned to each of the four rasters for the overlay. The job centers variable was assigned a significantly higher weight to compensate for the inadequate transportation services provided to Detroiters to commute to and from work.

Distance (m)	Score
0-100	9
101-200	8
201-300	7
301-400	6
401-600	5
601- MaxDist	1

Figure 7. The score assignment for the Important Destinations rasters.

Next, the job center raster for the entire study area was clipped to only include the study area outside of the Detroit city limits. This raster and the overlay raster within Detroit were mosaiced together into a single dataset. From this layer, 191 destination points were manually created. They were created manually in order to ensure they were placed on top of a road that we had determined to be suitable for a bus route.

4.2 Demographic Data

The rationalization for the selection of the transits origin locations were based off of three primary variables; population density, percent African American, and median household income.

These characteristics were chosen as a way to best address the shortcomings of the current bus system, with the intention of forming bus routes that passed through or near areas of higher population density, lower median household incomes, and higher African American populations. For all three variables, data was imported from the 2016 US Census, and was organized by census block groups. The data was first projected into the project's coordinate system, UTM Zone 17N, then assigned pixel scores. Each of these three categories were divided into five quantiles, and every pixel score category contains an equal number of enumeration areas; for example if there were 100 enumeration areas, twenty would have a pixel score of five, twenty would be a four, and so forth. The Median Household Income variable was measured in US dollars per year by census block group, and was compiled from US Census Bureau data. The data ranged from \$0 as the lower limit of the lowest quantile, to highest quantile's upper limit of \$233,000. Seeing as this project aimed to provide higher transportation access to lower income areas, the lowest quantile, comprised of the block groups with a median household income of \$0-\$26,250 per year, were assigned a pixel weight of 5, and weightings were incrementally lowered by one as the quantile average income increased. Population density was measured in people per acre and ranged from 0 persons per acre as the lowest limit of the lowest quantile, to 52.5 persons per acre as the upper limit of the most dense quantile. Following the logic that census block groups with higher population densities should have a higher priority for transit routes, we assigned census blocks with the highest population density, 10.75 to 52.5 people per acre, the highest score of 5, then incrementally decreased the score by one as the quantile density decreased. Finally, the percentage African American variable was weighted giving priority transit access to census block groups with the highest percentage of African Americans. This

variable scaled from an assigned score of 1 for the lowest quantile, encapsulating a range of 0 to 20% African American population, to the top quantile of 80-100% African American, which was assigned the highest score of 5.

Median Household Income (usd/year)	Population Density (people/acre)	Percent African American (%)	Score (1 - 5)
\$0 - \$26,250	10.75 - 52.5	80% - 100%	5
\$26,250 - \$41,500	7.8 - 10.75	60% - 80%	4
\$41,500 - \$55,972	5.4 - 7.8	40% - 60%	3
\$55,972 - \$78,125	3.14 - 5.4	20% - 40%	2
\$78,125 - \$233,000	0.0 - 3.14	0% - 20%	1

Figure 8. Demographic data scoring.

After assigning each variable their respective pixel scores, a weighted overlay of the three layers was performed to create the origin demographics raster. The overlay weights were assigned based off of the criteria of relative importance in the scope of this project. Given that population density would provide the most people with the most access to transit, this layer was considered to be the most important, and was awarded a weighting of 36%. The percent African American and Median Household Income layers were each assigned a weight of 32% under the justification that both of these groups are significantly disenfranchised but also because these two layers contain a significant level of spatial overlap. After converting the three data layers

into one weighted raster layer with a cell size of five meters, a point layer was then created. Using the raster layer showing “hot spots” of targeted origin locations, the point layer was populated by manually placing points in areas of high interest on roads of higher suitability. Origin points were snapped to the road suitability vector layer, giving higher priority to more suitable sections of roads while trying to be reasonably centralized between census block groups showing higher levels of variable scores. Distance between points were spaced in an attempt to prevent over-saturation of points in an area while still being relatively equal in the distance from any block group to surrounding points. The resulting vector layer was comprised of 173 different locations which would serve as the demographic origin points for the final route creation. The weighting of the variables used for the raster overlay can be seen in tabular form in Figure 3 in section 2.2 of this paper.

4.3 Road Suitability

The road suitability implementation involved analyzing and scoring each variable comprising suitability and combining them to create one score of suitability. The output was used to create a Network Dataset which new routes were constructed on. The road suitability score for each road segment was added as an extra attribute in the layer. The scoring for each respective attribute can be found in Figures 9, 10, and 11. For pavement condition, suitability was considered in a positive linear relationship with the PASER score of 1-10, 10 being the most suitable as a perfect condition surface to travel on. Our data on number of lanes had values of 0-8 for all road segments considered suitable. The highest weight was assigned to road segments with 3-5 lanes with the relative weights reducing out from that range. Road segments with 1 or 2 lanes were scored lower for being lower flow, and roads with more than 5 lanes were also

weighed relatively lower for being too heavily trafficked to implement a bus route. They could also be above ground, interstate highways that were misclassified in the data from SEMCOG. National Functional Classification was considered from values of 3-7. The values 1 and 2 are interstate highways so these were excluded from suitable roads entirely. The highest scores were placed on roads with NFC values from 3-5. Values of 6 and 7 constitute residential roads, so they were also weighed relatively lower. Once the variables were scored into a uniform scoring schema, a separate field was created to weight each variable according to the decided weights from Figure 5. This created an attribute of road suitability which was then established as our impedance to travel in the Network Dataset when developing new bus routes. Because the suitability variable needed to be considered as an impedance to use the Network Analyst dataset, the scoring for each variable of road suitability was done in reverse, meaning the lowest score constitutes the least barrier to travel and thus the highest suitability.

Weight values are the impedance level to cross that value, so lower weight constitutes higher suitability

Classification	Weight
3	20
4	10
5	0
6	40
7	70

Figure 9. NFC Classifications and Scale

Number	Weight
0	100
1	70
2	50
3	30
4	20
5	0
6	50
7	70
8	100

Figure 10. Lane Number and Scale

Rating	Weight
0	100
1	90
2	90
3	80
4	70
5	50
6	40
7	30
8	20
9	10
10	0

Figure 11. PASER Rating and Scale

4.4 Route Production

Once each road in the study area had been assigned a score, the Network Dataset along which bus will be routed was created using the roads vector layer. Connectivity was defined as any vertex, so that any bus site on a road was considered connected to the network, even if it is only on a vertex and not an endpoint. Elevation was ignored for the purposes of this model. Two attributes were incorporated into this dataset: Length and Suitability Score, both as cost type attributes. Length was measured in meters. The Suitability Score was measured in minutes

despite not being indicative of the time it would take to travel from point to point. Among the available units, however, minutes was the most suitable because the lower the suitability score, the lower, the more suitable the road was considered. This is similar to the relationship between time and suitability; less time makes a route more suitable. Furthermore, in order to create routes using Network Analyst, the Network Dataset needs to include a time attribute. A custom travel mode was created for this dataset where the impedance was set as the Suitability Score attribute. U-Turns were not allowed for the established transportation mode.

After creating the Network Dataset, the next step was to define Service Areas for each bus route. Using the Generate Service Areas tool in ArcMap, the origin points were used as the facilities input, and the break value was set to four miles. The resulting vector layer was a series of polygons that represented the maximum possible extent of each bus route.

Next, ArcPy was used to iteratively generate a feature class of points for every generated service area. The points in the feature classes were both the origin and destination points contained in each Service Area. Then, also using ArcPy to automate the process, a route was generated for each feature class. The Find Routes tool was used. The points within each Service Area were used as the stops, and it was specified that the points could be reordered, and that the routes should return back to the first point along the route. At this point, 148 routes were created. If a route had been generated for every Service Area, there would have been 173 routes, but Service Areas with less than two points were excluded. These 148 routes served as the rough draft for the final output. Many of the routes included advanced road maneuvers, like U-Turns, that are neither realistic nor safe to be performed by city buses, and therefore required heavy editing. Figure 12 illustrates an example of the editing results. Each bus route was manually

edited to exclude U-turns and excessive overlap within itself in order to create routes that did not overlap on themselves unless necessary, and formed a general loop connecting the majority of the points of interest addressed by the originally generated route. If a generated route appeared especially similar to the result of an edited route or other generated route, it was deleted so as to prevent redundancies and oversaturation. The final layer of compiled routes was comprised of 127 edited bus routes that extensively covered both the city of Detroit as well as the target regions of the outlying suburban counties.

Edited vs. Generated Bus Routes

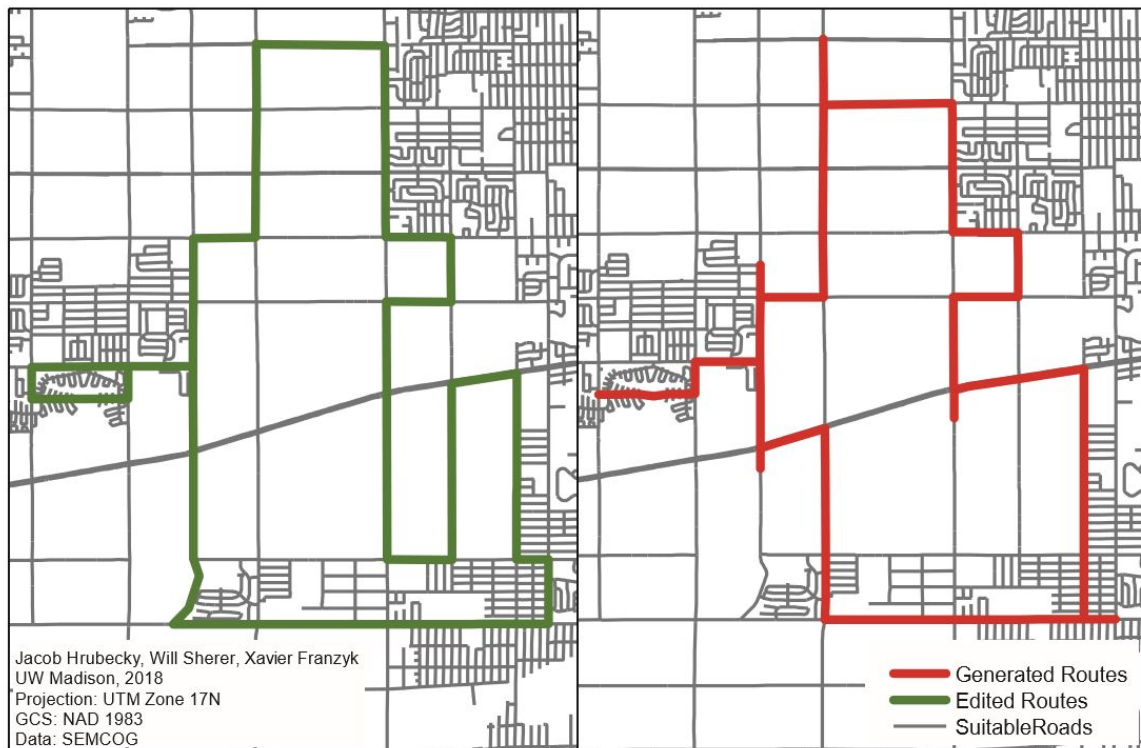


Figure 12. An illustration of the editing process that each generated route underwent.

5.0 Results, Analysis, and Discussion

5.1 Analysis and Results

While the main output of this project is the network of bus routes designed to service Detroit and the surrounding areas, there are also several other output datasets that provide insight into the final product. First and foremost, the origin and demographic rasters represent both where people want to go, in addition to where they live. Figure 13 highlights the fact that while most people live near the city center, there are also higher concentrations outside of the city. Figure 14 highlights the distribution of important destinations in and around Detroit. This data illustrates the fact that many jobs that employ Detroiters exist outside of the city. Figure 15 displays our road suitability layer in Metro Detroit and the surrounding immediate suburbs. The figure illustrates some of the classification trends, i.e. local residential roads being less suitable and a mix of suitability in other streets based on the variance of attributes. Figure 16 displays our final output of generated bus routes. Compared to the original bus routes illustrated in Figure 17, it is clear that the new bus routes serve a significantly larger area than the routes beforehand. Furthermore, by using our weighted overlays of important destinations and key origins, the new bus routes are guaranteed to serve the necessary areas, enabling Detroit's population to travel to and from their intended destination much more conveniently.

Origin Demographic Data Scores to Determine Origin Points

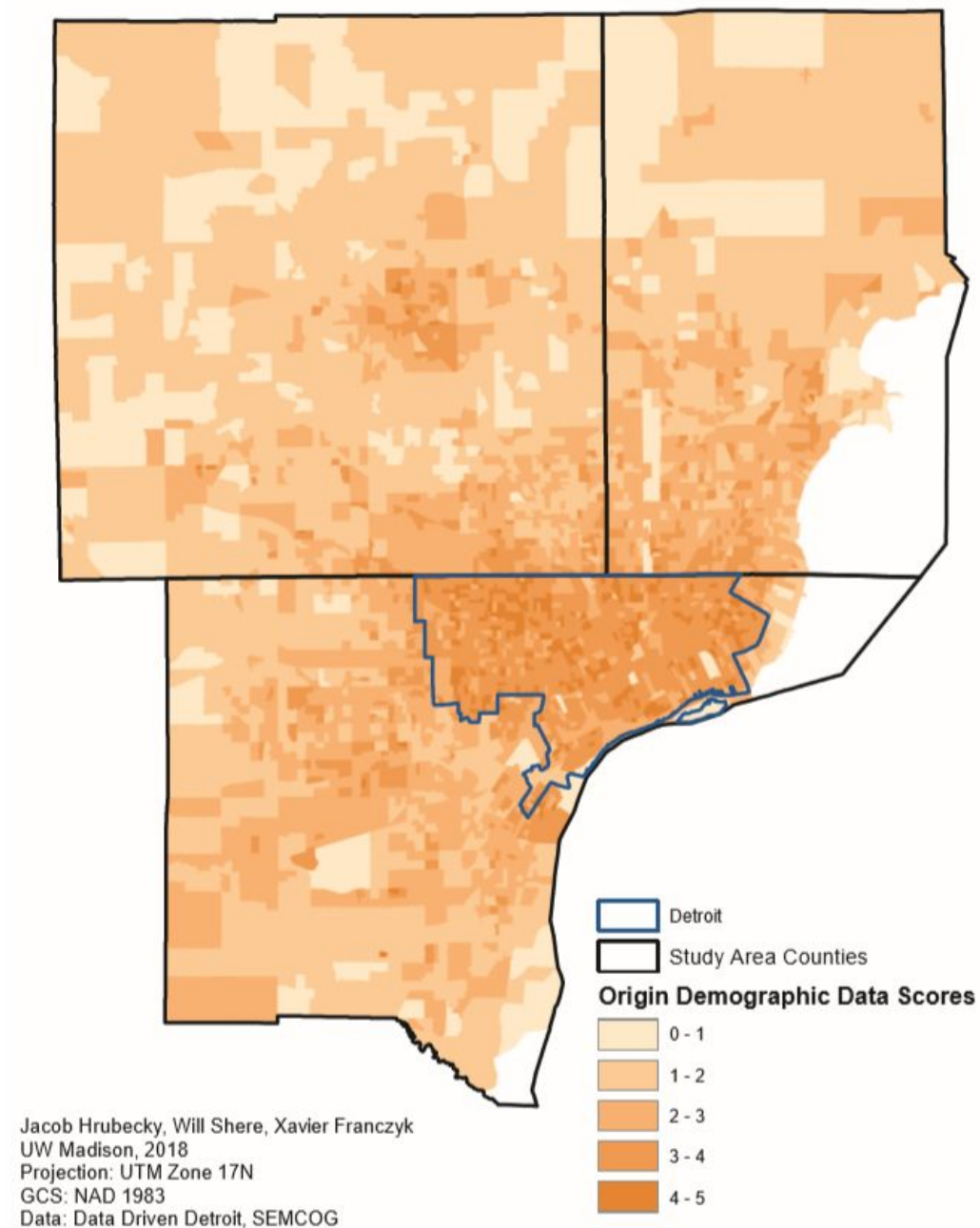


Figure 13. Distribution and concentration of study area residents determined to be most likely to need access to public transportation

Location Scores to Determine Destination Points

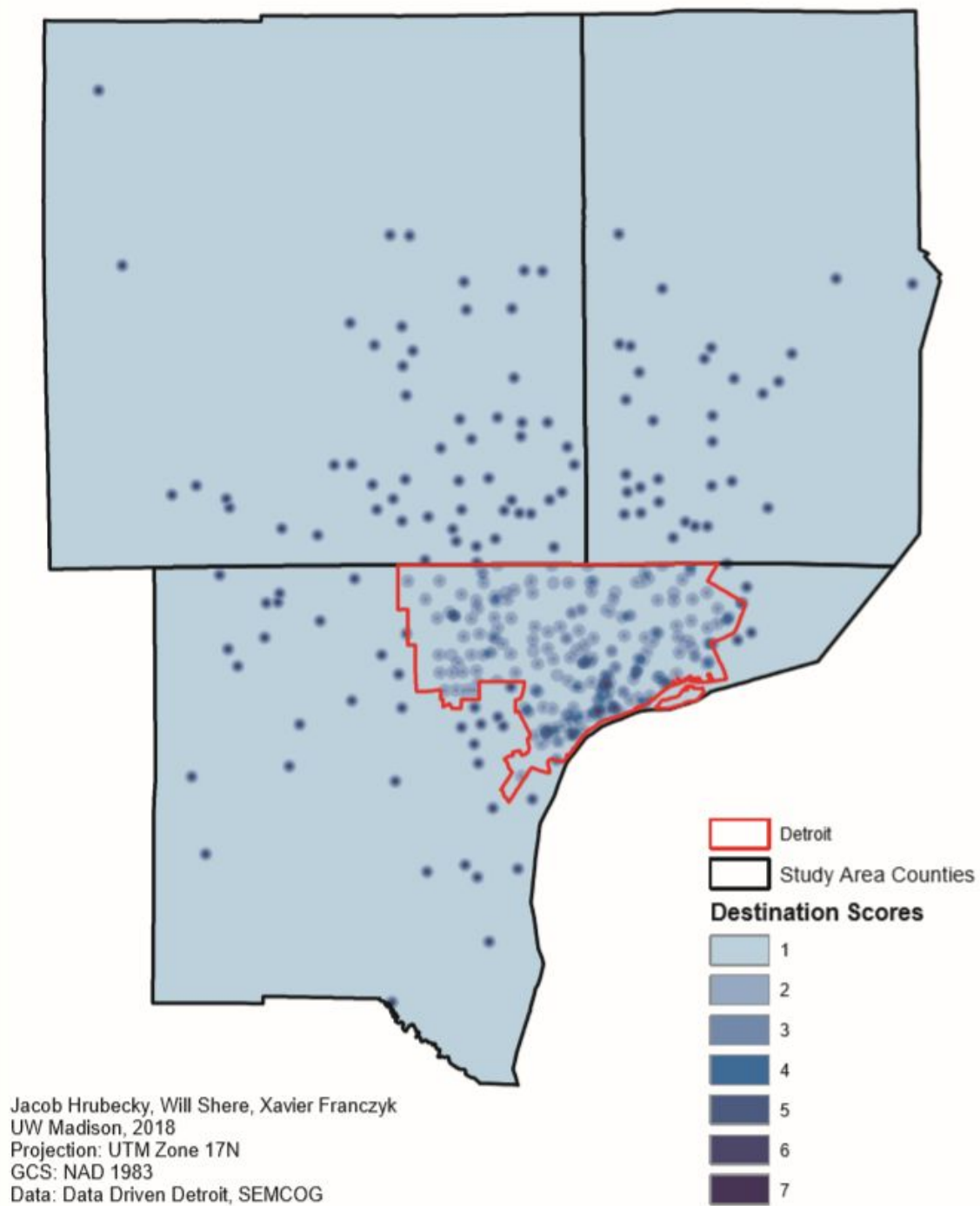


Figure 14. Map highlighting the distribution and concentrations of important destinations in the study area.

Suitability of Roads for New Bus Routes



Figure 15. Map illustrating a snapshot of the road suitability classifications.

Final Bus Routes (127 Total)

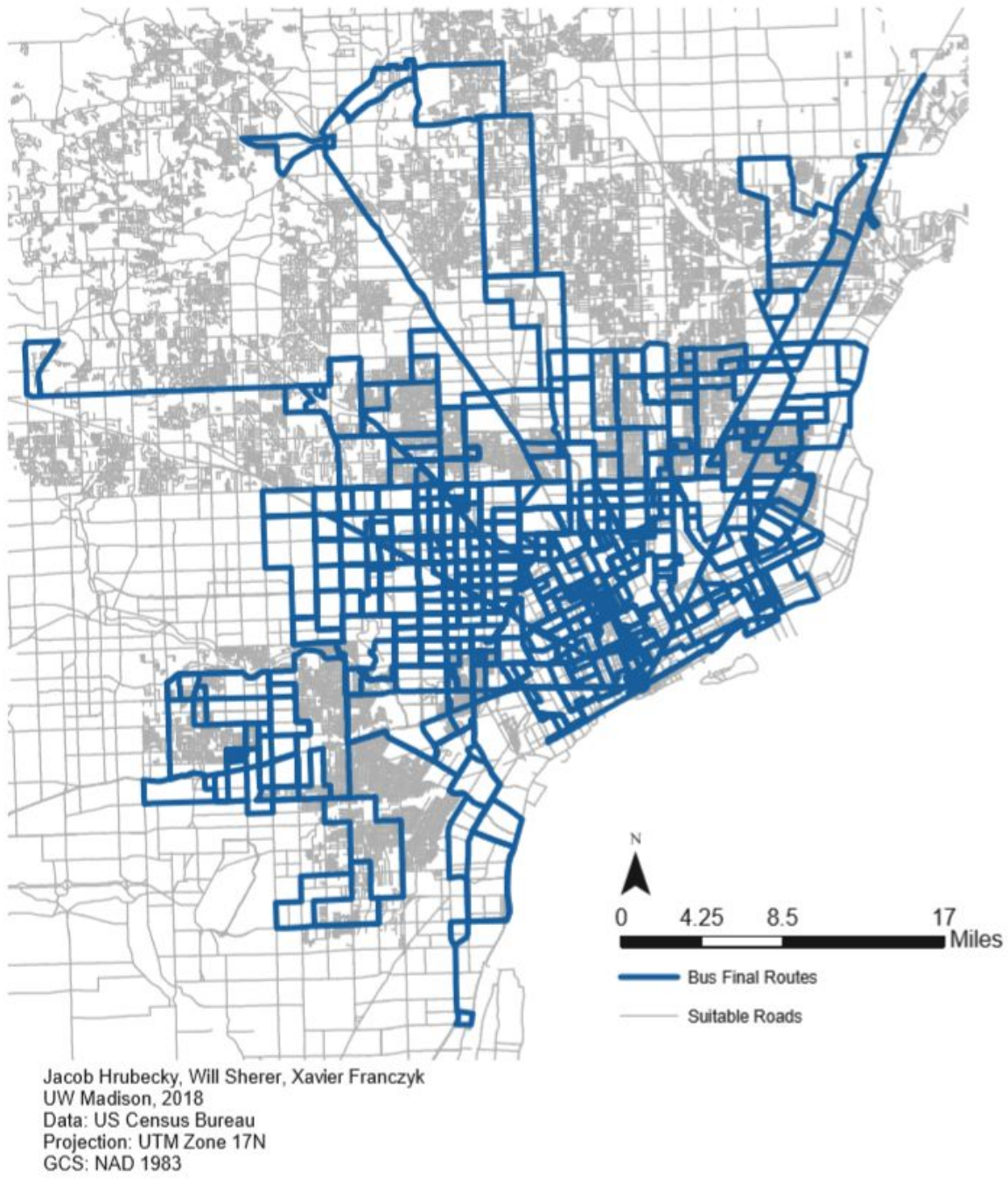
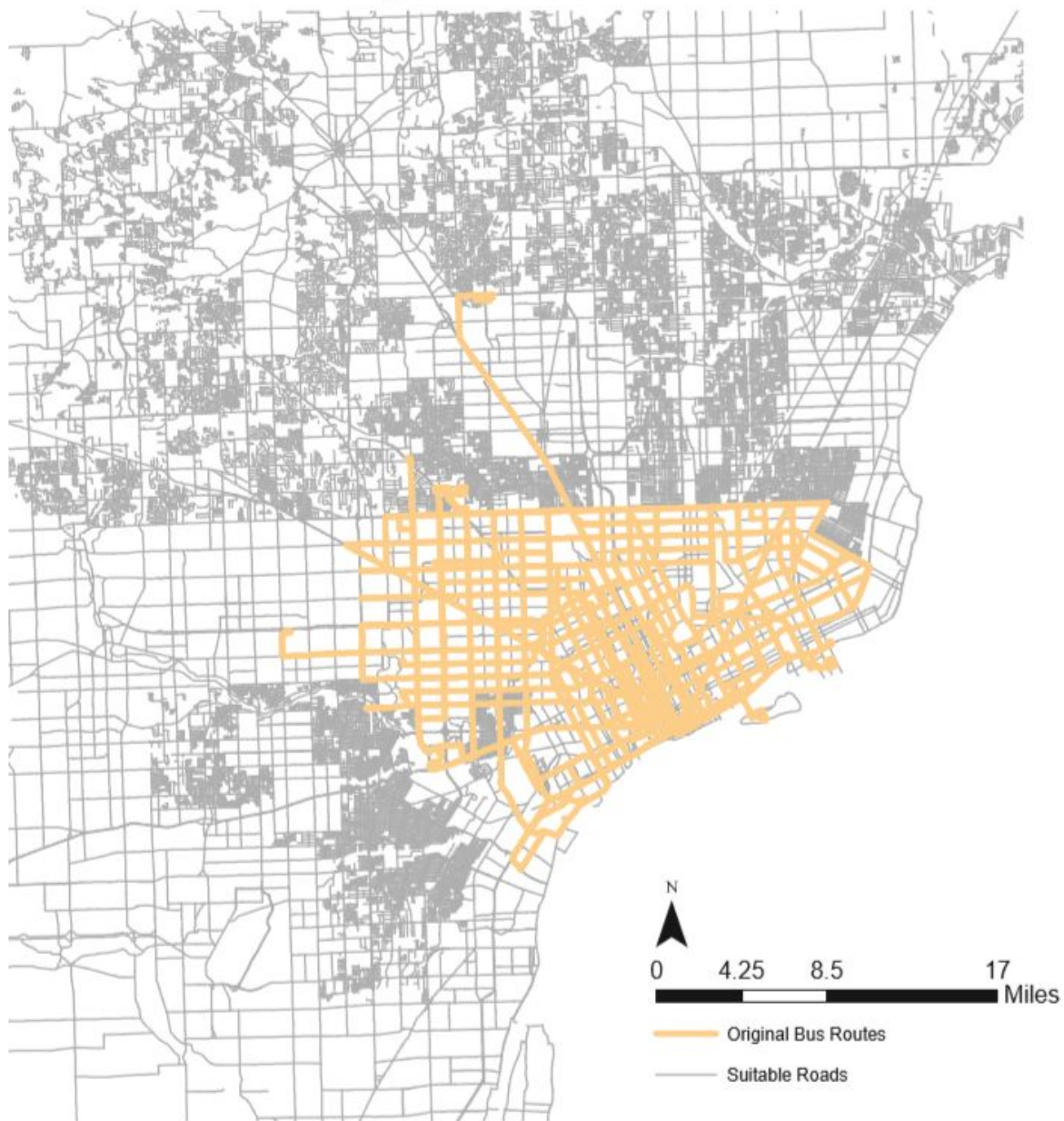


Figure 16. This is a map representing the final output of this project: new bus routes that serve Detroit and extend far into Wayne, Macomb, and Oakland counties.

Original Bus Routes



Jacob Hruby, Will Sherer, Xavier Franczyk
UW Madison, 2018
Data: US Census Bureau
Projection: UTM Zone 17N
GCS: NAD 1983

Figure 17. Original Detroit Bus Routes. These routes rarely leave the city despite the fact that many Detroiters commute to work outside of Detroit daily.

5.2 Discussion

While the final product of the research project addresses the project goals that were originally set, there are a few things that should be addressed had the researchers had more time. The biggest limitation of this project is the lack of ground truthing for the areas to be served. Given the geographic distance between the subject region of Detroit, Michigan and where this project was conducted, in Madison, Wisconsin, none of the group's researchers were able to travel to Detroit to see first hand the faults of the city's original bus system. This also means that no ground-truthing was conducted to verify the suitability of proposed bus routes, nor to identify locations where bus routes may be needed that were not reflected by census data. As with any research dealing with large crowd-sourced or survey-based data sets, there is a potential for error lying in both the accuracy of crowd sourced data as well as in response bias associated with the US census.

Given more time and computing power, the process of using Service Areas to create routes may also have been improved upon. Service Areas were used because it was known that they would overlap. It was important that bus routes intersect one another in order to create locations at which riders could transfer buses. However, it was difficult to control the degree with which routes were overlapping. In some areas, routes may overlap too frequently, and other may not intersect each other often enough.

Furthermore, due to the large geographic extent these bus routes were designed to cover, the implementation of a Bus Rapid Transit (BRT) system would complement their functionality and efficiency. BRT's are designed to carry riders at higher speeds, over longer distances, and with less stops. Many of the routes travel through areas with small populations

and few jobs. These are not regions where bus stops are necessary and the commute out of the city to work for Detroiters could be improved even more by operating these routes as BRT's.

6.0 Conclusions and Future Research

6.1 Conclusions

This project set out to design new bus routes for the city of Detroit, Michigan, using a site suitability analysis. The researchers aimed to use geographic information systems to broaden the extent of bus routes while providing demographically equitable access to employment centers, healthcare facilities, grocery stores, and government buildings. This project was designed to focus on providing access to employment centers both within the city of Detroit as well as in the suburban communities of the outlying Wayne, Macomb, and Oakland counties, and it specifically looked at Detroit's African American population as the demographic target for improved public transportation access.

6.2 Future Research

Given more time and resources, each route would be analyzed with ground analysis for its feasibility. Ideally each route would be analyzed for its suitability based on more detailed understanding for each service area. This would involve analyzing the demographics for each service area individually and evaluating the feasibility on the ground for each route. Some routes would likely be eliminated and others combined into a more effective routes and service area. The output of this project is still fairly unrefined based on the information available at the time of its completion, so a more detailed analysis of each service area based on its real-world attributes would likely make the new routes more effective at serving our target demographics.

7.0 Acknowledgements

This research could not have been conducted without the assistance of all who contributed to the Detroit's geodata portal; Data Driven Detroit. The data provided through SEMCOG was also essential to this project's success. This data was instrumental in the synthesis of the project's final bus routes, and saved the researchers an incalculable amount of time in the collection and processing of destination data. This research would also not have been possible without the direction and guidance of the class's professor, Bill Gartner. Bill was extremely helpful in workshopping the implementation strategy of the project as well as acquainting the group with ArcGIS' Network Analysis software.

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