# A LAND USE SUITABILITY ANALYSIS APPROACH FOR LOCATING POTENTIAL RAIL TRANSIT ROUTES IN THE DETROIT METROPOLITAN AREA

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ABSTRACT

A LAND USE SUITABILITY ANALYSIS APPROACH FOR LOCATING POTENTIAL RAIL TRANSIT ROUTES IN THE DETROIT METROPOLITAN AREA

by Thomas Nantais Jr.

Modern day transportation systems are characterized by a heavy dependence on the personal vehicle which has numerous negative impacts such as traffic congestion and degradation of the natural environment for large expanses of road networks. The implementation of a properly planned rail transit network could counteract some of these adverse consequences while improving the connectivity or linkages of Detroit and the surrounding feeder areas and promoting more compact development. Geographic information systems (GIS) provide a platform to carry out suitability analysis for such a network. The goal of this study was to use GIS and publicly available data to ascertain alternate transit routes in the Detroit metropolitan area. Multiple criteria found to be significant in past studies were used as a foundation for this study. These criteria encompassed land use diversity, environmental, economic, and potential ridership themes. A GIS was used to map, then overlay, these criteria and weight them varyingly to emulate multiple stakeholder visions. This was necessary as planning is a public process in which many groups take part. An optimal route was derived for each stakeholder vision using the least cost path derived from the underlying criteria maps. The criteria for each stakeholder vision were attributed to the routes to derive an associated cost for each route and to compare routes. The study provided a method for deriving alternate transit routes and quantifying those routes using a length weighted mean (LWM) technique. The LWM attributed an average cost factor to each route as a function of the cost raster produced for each vision and the length of each route. It was found that quantifying the routes with associated cost values may prove to aid in the planning process by providing insight on alternative options.

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# CHAPTER I

## INTRODUCTION & BACKGROUND

Transportation is a daily consideration for the majority of the populace. In the United States, and many other nations around the globe, a primary reliance is placed on the automobile. The continuing population growth and accompanied automobile ownership have yielded significant transportation issues. Traffic congestion, a principal transportation concern, is evident in many urban areas of the United States. Another issue that arises from a heavy dependence on the automobile includes environmental degradation which manifests through excessive exhaust emissions and the destruction of natural habitat for large expanses of road networks.

A recommended solution for many of the negatives of urban transportation systems is a shift to a multimodal system (Horner and Grubesic 2001; Murray 2003; Farhan and Murray 2005). A multimodal system refers to a transportation scheme that incorporates a mixture of personal and public transport options. This could have numerous benefits such as alleviating traffic congestion, reducing our ecological footprint, and promoting more thorough connectivity of a locality or region. In order to assess and tackle spatial issues that arise from transportation systems management and planning, it is beneficial to use relevant approaches and technologies. These may include multi-criteria decision analysis, spatial decision support systems (SDSS), and database management systems (DBMS). Multi-criteria decision analysis (MCDA) is a procedure for structuring decision problems based on multiple criteria and then providing and analyzing alternative decisions (Malczewski 2006). A DBMS offers a platform for storing and managing data. A SDSS provides a platform for using spatial information to aid in the decision making process.

With that being said, a geographic information system (GIS) is an ideal tool for transit planning as it can considered as both a spatial decision support system and a database management system. Geographic information systems provide a platform for storing, managing, manipulating, analyzing, and visualizing spatial information. “The interdisciplinary field of geographic information systems for transportation (GIS-T) has emerged to focus on the role of GIS in transportation analysis and planning” (Miller 1999, 374). A very promising application of GIS for planning is land use suitability analysis (McHarg 1969; Hopkins 1977; Brail and Klosterman 2001; Collins et al. 2001; Malczewski 2004). Land use suitability analysis generally refers to the process of assessing the appropriateness of an area for a desired future land use based on a set of predetermined criteria (Hopkins 1977; Hopkins et al. 2001; Malczewski 2004). In this light, merging GIS-T with the principles of land use suitability analysis provides a foundation for making educated decisions regarding the complexities of transit planning.

## Problem

In the majority of U.S. cities, public transit is significantly underexploited (Murray 2003). Detroit, Michigan and the associated metropolitan area can be lumped into that category. Currently, the two forms of local public transit in Detroit are a less than satisfactory bus network and the People Mover. The latter is an elevated light rail system that runs for under three miles in a city that covers roughly 140 square miles. A light rail plan, named the M-1 RAIL, has been proposed by the Detroit Department of Transportation (DDOT) which would run along Woodward Avenue from downtown Detroit to the New Center district. Although the plan has not been approved as of yet, U.S. representative Hansen Clarke stated "I believe [the M-1 line] could be the anchor for regional transit in southeastern Michigan. It's the potential it represents;

it's a starting point for a regional transit system" (Abbey-Lambertz 2012). Also, regional-scale commuter rails have connections in Detroit. However, a rapid rail system that runs through Detroit while providing linkages to the surrounding feeder areas has not been proposed.

Metro Detroit covers a large area in the southeastern region of Michigan and is home to an overwhelming proportion of the state's population (US Census Bureau 2010). The subset of the metropolitan area being considered includes Wayne county and the five nearest counties, with a combined area of roughly 3,900 square miles (Michigan Center for Geographic Information 2011). It is comprised of various origin/destination locations for both work and non-work travel. To date, the only feasible means of traversing the aforementioned region is to use the built road network, which lends itself to the issue of traffic congestion. Traffic congestion in itself can undermine the efficient connectivity and accessibility of a region. In this sense then, the relatively limited extent of the existing and proposed light-rail systems do little to enhance the multi-modality, connectivity, and accessibility of the Detroit metropolitan area. In terms of transportation, accessibility refers to the ease of reaching destinations.

## Purpose

The goal of this study is to use GIS and land suitability analysis to identify potential corridor and station locations of a rapid rail transit system in Metro Detroit, a specific application on which research does not currently exist for the region. "A rail transit system may be a useful and efficient alternative that can provide fast, reliable, and convenient service for populations to important places in an urban area" (Sutapa and Jha 2008, 81). This region is a good candidate for such a project for multiple reasons. The region has large tracts of land, even within the Detroit city limits, that are either vacant or not being efficiently utilized. The public and private costs of land acquisition for such a major project in a built environment are relatively easy compared to other regions.  Also, Detroit has a significant population, an estimated 58,000 residences who do not own personal vehicles (U.S. Census Bureau 2010).  These inhabitants would benefit from a rapid transit system with respect to accessibility and mobility, and would generate a demand for such a transit system.

This study aims to incorporate a multi-objective approach which is necessary for a planning project.  Multiple objectives based on different variables provide a means to represent the interests of multiple groups with stakes in such projects.  The objectives used in this study are a combination of the following:  alleviate traffic congestion by implementing a different, yet competitive modal choice, improve connectivity of the region, keep the environmental impacts to a minimum, and promote transit-oriented development.  Although the budgetary costs associated with such a project play a large role in deciding whether or not it will be implemented, they are not directly taken into consideration due to temporal and monetary constraints of the data collection.

# CHAPTER II

# LITERATURE REVIEW

Past studies support the idea that the implementation of properly planned multimodal transportation systems is a viable alternative to help manage some of the adverse consequences of current transportation systems characterized by a heavy preference towards the personal vehicle (Horner and Grubesic 2001; Farhan and Murray 2005; Verma and Dhingra 2005; Rosenberg and Esnard 2008; Sutapa and Jha 2008; Lutin et al. 2008; Farkas 2009). Although various methodological approaches have been employed, these studies pointed out that transit planning is very complex. Many different variables need to be taken into consideration including demographic, political, and social factors.

## Transit Site Selection

Lutin et al. (2008) explored a measure that shed light on the selection of appropriate transit investment areas by calculating a transit score for the study area. The initial equation was simplified using correlation analysis and the coefficients were determined using regression analysis. The study pinpointed three demographic variables that could be used as a predictive measure for potential future transit sites. The three independent variables that influenced the dependent variable, transit potential, were population density, job density, and density of zero car households. The transit scores were ranked into five categories and mapped at the census tract level for visual inspection and potential site selection (Lutin et al. 2008). This study yielded some interesting results and further justified that higher population and employment densities are more conducive for transit systems. On the other hand, it did not address issues pertaining to current land ownership and land use, environmental limitations, or corridor site selection.

In a study performed by Rosenberg and Esnard in 2008, a hybrid scoring methodology for transit site selection was utilized which incorporated proximity, developability, and visual quality measures. Proximity scores were based on a quarter mile walking distance to transit-associated facilities, entertainment areas, businesses, and residential areas. The visual quality scores addressed aesthetic values, perceived safety, connectivity, and accessibility. However, these were not quantitative measures and seemed to be purely subjective. Mode choice itself is subjective, but capturing such qualitative measures becomes difficult and highly variable. Developability scores were based on land use, availability, cost, parcel size, and ownership. The rationale behind this was logical as land acquisition for a transit project poses a significant problem. The three scores were combined to yield an optimal station site. The study did well to identify an optimal station site based on the predetermined possible locations, but did not address rail corridors between sites.

## GIS & Suitability Analysis

A 2009 study performed by Farkas combined GIS techniques with spatial multi-criteria decision analysis (SMCA) for rail route/site selection. The study area included the rapidly growing city of Cochabamba located in Andean Bolivia. The SMCA analysis included economic, engineering, institutional, social, and environmental factors in which a specific criterion was used to represent each objective. The respective factors used were projected construction costs, engineering characteristics and geological soil structure, a connectivity index, population density, and ecological suitability. The criteria were weighted by a group of expert engineers and economists. GIS was used to display and overlay the weighted criterion maps to yield a composite suitability map from which alternate potential rail routes were identified.

After the corridors were chosen, final locations of metro stations were fixed within the corridors based on the suitability of the underlying raster suitability layer. Further, network analysis was performed to compare the alternative routes.

In a master's thesis published in 2007, Keshkamat performed a multi-criteria spatial analysis of possible locations for a regional expressway system in northeastern Poland. Assessment criteria were mainly identified through communications with environmental assessment specialists, researchers, and planners. Like Farkas, alternative routes were proposed relative to differing stakeholder visions. The following visions or themes were modeled: transport, ecology, social and safety, and economy. The transport objective took into account proximity to transit and current traffic density. Protected and natural areas, wetlands, and water were used to represent the ecological vision. The social and safety theme reflected more intensely urbanized areas, population served, and hazardous areas. Economic indicators included soils, agriculture status, construction costs, and so forth. Four suitability maps were generated with the same criteria; each theme was weighted differently based on the stakeholder vision being depicted. A road vector layer for the study area was then overlaid on the suitability maps. The Hawth's Tools extension in ArcGIS was used to calculate "line weighted means (LWM) from each resultant suitability map to the road vector layer. This attributed the mean (suitability) value of each resultant vision to each segment of the line based on its location" (Keshkamat 2007, 39). Since a least cost path was desired, the suitability values were inverted which translated them into impedance values. The Network Analyst extension in ArcGIS was used to formulate one optimal route per stakeholder vision. Utilizing the impedance cost function, an optimal route was one in which lower route impedances were viewed as superior.

# CHAPTER III

# METHODOLOGY

## Study Area

The Detroit metropolitan area, also referred to as Metro Detroit, is one of the main urban areas in the Great Lakes region of the United States. It covers a large portion of the southeastern region in the lower peninsula of Michigan. The study area is comprised of six counties located within the Detroit metropolitan area, covering around 3,900 square miles (Michigan Center for Geographic Information 2011). These include Livingston, Macomb, Monroe, Oakland, Washtenaw, and Wayne Counties. These six counties, out of a total of 83 for the entire state, are inhabited by 4,541,703 people, roughly 46% of Michigan's 9,883,640 people per the 2010 Census.

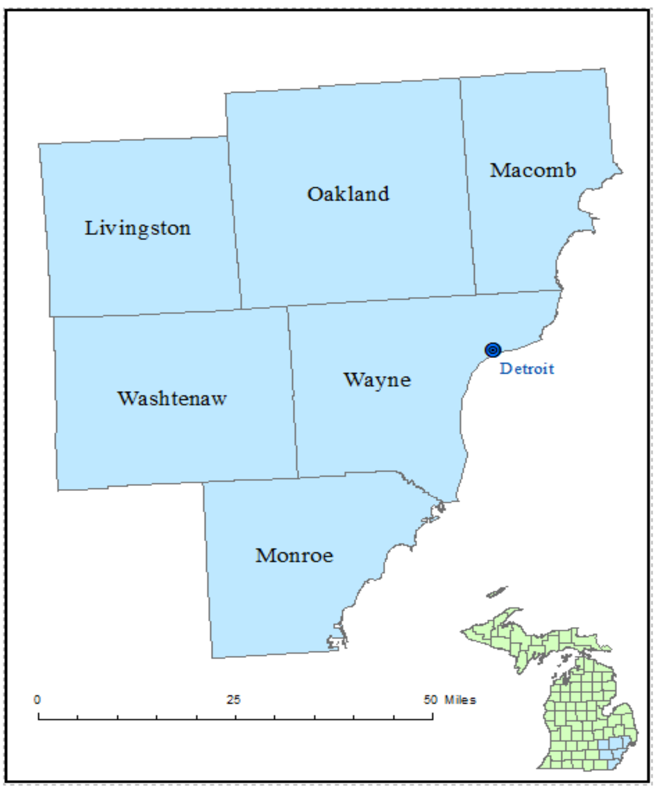


Figure 1. Study area

## Data Description

Land use data for the study area was compiled from the Southeastern Michigan Council of Governments (SEMCOG). The latest available data were from 2008. SEMCOG provides online data for Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties. Originally, the data were created at the parcel level. The data were then aggregated based on common land uses and city codes to remove any resemblance to the individual parcels before being made publicly available. The data consists of ten general land use classifications: agricultural, airport, commercial, governmental/institutional, industrial, single-family residential, multiple-family residential, parks/recreation/open space, transportation/communication/utility (TCU), and water.

Longitudinal Employer-Household Dynamics, or LEHD, Origin-Destination Employment Statistics data (LODES) are provided via the United States Census Bureau. The relevant component of the data consists of total number of jobs associated with both a work and a home census block. A work block describes the census block unit in which a job is located while a home block describes the census block unit where the worker resides. The data are available for the entire country by state up through the year 2009. To keep the results of the study as recent as possible, the data from 2009 were used.

Road network and railroad data for the state were collected online from the Michigan Geographic Data Library provided by the Center for Geographic Information in the Department of Information Technology (CGI). The county boundaries for the state were also downloaded from CGI.

## Data Preprocessing

Since only the study area was of concern, the initial data had to be subset. To obtain the extent of the study area, the county boundaries (Livingston, Macomb, Monroe, Oakland, Washtenaw, and Wayne) were downloaded from CGI. A dissolve function in ArcMap was applied to the county boundaries to produce a layer containing one outline of the entire study region. The vector layers (i.e. roads, railroads, and land use) were clipped in ArcMap using the study boundary previously mentioned. The outputs were the desired extents of roads, railroads and land use data. The roads and railroads layers were then merged together to formulate a transport layer.

The initial origin-destination data contained upwards of 3.3 million records as the dataset portrayed statewide work block to home block commutes. Microsoft Access was used to query the data to significantly reduce the data size to the home and/or work blocks which fell within the study region. Ultimately, the desired output was an urban intensity layer which portrayed the number of jobs and/or residents per unit area. However, multiple processes had to be completed to arrive at this desired output. Joining the original data to the blocks shapefile would not suffice as a join function in ArcMap is inherently a one-to-one process. As would be expected, many of the blocks had multiple associated records necessitating a function that would capacitate one-to-many relationships. To maintain the simplicity of data interpretation, the data were modified into the previously mentioned urban intensity values so that a join function could be utilized.

First, the number of jobs had to be summarized by both the work block and by the home block. These two processes were carried out separately in ArcMap by summarizing each block field and including a summary statistic, which was the sum of the number of jobs associated with each block. The result was two tables; one with the total number of jobs by work block and another with the total number of jobs by home block. In simpler terms, the number of jobs associated with a work block indicated the number of workers or jobs per census block unit and the number of jobs associated with a home block indicated the number of working residents per census block unit. These two tables were joined to the census blocks shapefile for the study area. The total number of jobs by home block was added to the total number of jobs by work block. This summed value was divided by the area (in acres) to arrive at the urban intensity values, or the number of jobs and/or residents per acre. This was appropriate as urban intensity values are indicative of potential ridership. Past studies have shown in general, higher urban intensity values favor the shift to transit use and a lesser dependence on personal vehicle use (Frank and Pivo 1994; Newman and Kenworthy 2006).

## Data Rasterization

Before raster analysis could begin, all vector data needed to be converted into raster datasets with uniform extents and cell sizes and a common reference system. ArcMap was used for this data conversion. For the land use and urban intensity data, the "Polygon to Raster" tool was utilized. The cell assignment type was set to maximum combined area which was simply the method to determine how the value of a cell was assigned given that more than one value falls within any given cell. In this case, whichever feature has the largest combined area within the cell in question will donate its attribute to that cell. The "Feature to Raster" tool was used rasterize the transport layer. This tool uses a binary-like assignment technique; if the vector feature is at all contained in the proposed raster grid cell, that cell will inherit the designated attribute and all other cells receive a value of no data. The cell size for all raster layers was set to one quarter the size of the smallest significant feature among all of the vector data sets. This was determined to be approximately 20 meters.

## GIS-Based Land Use Suitability Approach

All other aspects disregarded, a rail transit system is simply composed of stations and the connecting rail lines. However, in order for such a rail transit system to be successful, it needs to be utilized. To ensure utilization, the network needs to be accessible and efficient. These goals can be reached by finding optimal or near-optimal site locations. In order to do so, multiple objectives/themes need to be considered. Four suitability maps were created in ArcGIS to represent each theme. The current study used land use diversity, urban intensity, environmental preservation, and economic themes which were similar to an approach used in Keshkamat's 2007 study. These themes emulate a factual representation of many of the factors that would be considered in planning the location of rail transit system. Various transit studies have incorporated similar factors which was why they were chosen (Cervero 2008; Cervero 2002; Farkas 2009; Guerra and Cervero 2011; Keshkamat 2007; Lutin et al. 2008; Rosenberg and Esnard 2008). Also, these themes could be modeled because the data were currently available for the study.

### Land Use Diversity Theme

The land use diversity theme sought to distinguish between urban and rural areas. More highly urbanized areas are characterized by a greater mixture of land uses and are inherently more highly populated than rural areas. In the current study, the degree of land use mixture was used to represent the land use diversity theme, drawing insight from Keshkamat's study. From a social standpoint, a higher degree of land use mixture was indicative of a more urban, or generally more populated, area. Population density was not directly used as an input for this theme as it was indirectly associated the measure of urbanization. In other words, it was generally assumed that a higher degree of land use mixture indicated a more urban and more populated area. This theme is important because more mixed use areas with associated higher population densities in general are more conducive for rail transit. A focal statistics map algebra function was carried out in ArcMap's "Raster Calculator" tool. The function worked with a square kernel size of 40 cells, or roughly half a mile. A half mile buffer size was used because that was considered a reasonable walking distance (APA 2006; Aultman-Hall et al. 1997). A variety function was used so that the new output raster values were a sum of the number of different land uses within a half mile of the cell in question. The output raster values ranged from 1 to 8. Since the higher the degree of land use mixture the higher the suitability, the classification of the output raster from this focal statistics function was left as is. For multiple suitability layers to be overlaid logically, the input layers must all have the same data range. So, the suitability range of 1 to 8 from this land use diversity layer was used as the standard range for all the following suitability layers.

Urban Intensity Theme

In this study the urban intensity, which is a density measure of employment and/or residents, was used to emulate potential ridership. Keshkamat used a similar approach in which traffic density was indicative of potential users, which would be referred to as potential ridership in transit studies. Newman and Kenworthy illustrated that urban intensities of roughly 14 residents/jobs per acre significantly reduces auto dependence (2006). Also, an earlier study demonstrated that between employment densities of 20 and 75 jobs per acre, there is a noticeable modal shift to transit use and above densities of 125 jobs per acre the mode choice shift to transit is very significant (Frank and Pivo 1994). These values were reflected in the classification of the data.

The urban intensity data, which described the number of jobs and/or residents per acre, were classified into seven classes using a Jenk's natural breaks classification and values greater than or equal to 125 were disregarded for the purpose of classification. Those values greater than or equal to 125 were set aside for the highest suitability value. This classification method produces classes that contain the least amount of variance between values in any given class (Cromley 1996). It is understood that urban intensity values of 125 and greater do not directly correspond to job densities of 125 or greater in relation to Frank and Pivo's study. However, the classification yielded very conservative classes as outlined in Table 1. The urban intensity values around 14 (residents and/or jobs per acre), which Newman and Kenworthy found to be significant in reducing auto dependence, received an intermediate suitability value of 4. The range of 20-75 jobs per acre, which Frank and Pivo found stimulated a significant modal shift to transit use, roughly corresponds to the suitability values of 5 and 6. Lastly, urban intensities of 125 or greater were reserved for the highest suitability class. The data were reclassified using the guidelines set forth in Table 1 to arrive at the final suitability map for urban intensity.

Table 1. Suitability classification values of the urban intensity layer

| Suitability Values | Urban Intensity Ranges |
|---|---|
| 1 | 0-2.183 |
| 2 | 2.184-5.525 |
| 3 | 5.256-11.455 |
| 4 | 11.456-23.472 |
| 5 | 23.473-44.012 |
| 6 | 44.013-75.770 |
| 7 | 75.771-124.999 |
| 8 | 125+ |

## Environmental Preservation Theme

The environmental suitability map used the rasterized SEMCOG land use data as input. This layer served to protect environmental areas. The data were reclassified into suitability values using the “Reclassify” tool in ArcMap. The park/recreation/open space, water, and agricultural areas all received values of 1 designating them as very unsuitable for transit sites. All other land uses received values of 8. The output was an environmental suitability map with either very suitable (8) or very unsuitable (1) lands.

## Economic Theme

Economic themes in transit studies evaluate areas based on incurred costs (Farkas 2009; Keshkamat 2007). Although construction costs carry significant weight in the transit planning process, they were not directly considered for this study. However outside of construction costs, the cost of land acquisition for such a transit project is very steep. In order to represent those areas with lower associated costs, land uses which were already being used for transportation were viewed as relatively cheap. The economic suitability map utilized a combination of two datasets. First, the transportation/communication/utility cells of the rasterized SEMCOG land use data were reclassified into high suitability (8) and all other land uses were reclassified to very unsuitable (1). To fill in any gaps, this layer was mosaicked with the rasterized transport layer to arrive at the final economic suitability layer. Before the mosaic was carried out, the transport layer needed to be reclassified. The cells representing the transport network were reclassified to high suitability (8) while all the remaining cells, which contained a no data value, were assigned a value of 1.

Stakeholder Visions

Planning in general is a very public process in which many stakeholders are involved. Different stakeholders have different ideas on what variables or themes should be considered more important in the planning process. Once the main factors had been established and the individual suitability maps for those themes had been generated, a weighted overlay function in ArcMap was utilized to form multiple composite suitability maps. These composite maps were a compilation of the land use diversity, urban intensity, environmental, and economic themes. In doing so, varying weights could be assigned based on what stakeholder vision was being portrayed. Drawing upon Keshkamats study, the four following visions were depicted: equal, economic, ecological, and social visions. Keshkamat derived weights for each of these visions through the inclusion of stakeholder priorities and the input from a panel of experts (2007). The same weights were utilized in this study and are displayed in Table 2.

Table 2. Criteria weights for the stakeholder visions

| | Equal Vision | Economic Vision | Ecological Vision | Social Vision |
|---|---|---|---|---|
| **Land Use Diversity** | 0.25 | 0.15 | 0.15 | 0.52 |
| **Urban Intensity** | 0.25 | 0.27 | 0.27 | 0.27 |
| **Environmental Preservation** | 0.25 | 0.06 | 0.52 | 0.06 |
| **Economic** | 0.25 | 0.52 | 0.06 | 0.15 |

The equal vision obviously gives equal weights to all criteria. The economic vision leans towards reducing costs and thus heavily weights the economic theme while giving very slim weight to the environmental factors. It goes without saying that the ecological vision seeks to preserve the natural environment and thus favors the environmental suitability input. It also gives the economic suitability the lowest weight. The social vision seeks to improve connectivity and accessibility. This vision heavily weights the land use diversity data, but also gives a significant weight to the urban intensity theme. It gives the least weight to the environmental suitability layer.

### Pinpointing Station Sites

After each vision was depicted with a composite suitability map, the rail station sites had to be localized. It was very apparent that those areas with the highest suitability values were clustered around city centers. In order to pinpoint station sites, some further processing needed to be done. The composite suitability maps were converted back into vector format using the "Raster to Polygon" tool in ArcMap. Only those areas with the highest suitability values were selected for each map and exported to a new layer. All but the land use diversity layer contained suitability values of 8; the land use diversity layer had a maximum suitability value of 7. The number of polygons with the highest suitability value ranged from 24 to 229. These areas needed to be minimized further as the construction of 24 or more stations was purely illogical. By selecting those records with a minimum area of 0.5 acres, the number of potential station locations was slimmed. Specific areas were chosen by cross-examining the composite suitability maps and the potential areas and then selecting the polygon with the largest area in each cluster. The selected polygons were converted to points using the "Feature to Point" tool in ArcMap. An optional parameter of keeping the derived point inside the confines of each polygon was selected to ensure that the derived station location remained in an area that was the most suitable. Five station sites were selected for the equal vision, and the remaining visions returned 7 station sites.

### Building the Corridors

The "Cost Path" tool in the Spatial Analyst extension of ArcMap was used to build the connecting rail line locations between stations. This tool calculates a one cell wide, least cost path between a source and a destination based upon two required raster layers: a back link raster and a cost distance raster. These raster layers were created using the “Cost Back Link” and “Cost Distance” tools, respectively. The backlink raster layer “defines the neighbor that is the next cell on the least accumulative cost path to the nearest source” and the cost distance layer “calculates the least accumulative cost distance for each cell to the nearest source over a cost surface” (ESRI 2012). As these tools use cost values and the composite maps were in suitability, the values had to be reversed using a reclassify function. Although the “Cost Path” tool can use multiple destinations as input, only one origin or source can be used at a time. Thus, to build corridors with more than one station along the same path, multiple least cost paths needed to be generated and mosaicked together.

Quantifying the Transit Routes

Once the transit routes were generated, the routes needed to be quantified. This was done by calculating a length weighted mean (LWM) for each route. The “Intersect Lines with Raster” command in the Geospatial Modeling Environment (GME) software was used to carry out this process. This tool required a vector line layer and raster layer as input. To derive the vector layer, the least cost paths were converted to lines using the “Raster to Polyline” tool in ArcMap. Since a single LWM, or impedance value, for each route was desired, each polyline cost path was dissolved into one record. The GME tool cuts each route into segments based on the vector layer’s intersection point with the underlying raster grid. The equation is as follows:

$$\bar{\boldsymbol{x}} = \sum_{\mathbf{1}}^{\boldsymbol{i}} (\boldsymbol{l_i v_i}) / \boldsymbol{L}$$

Where $\bar{x}$ is the length weighted mean, $l_i$ is the length of the line segment $i$ contained by a raster cell, $v_i$ is the suitability value for the underlying raster cell, and $L$ is the total length of the path. The higher the LWM, the higher the impedance or cost associated with the route. Once impedance values were calculated for each path using its own cost surface, impedance values were calculated for each path using the cost surface of the three remaining visions. This was done to gain some insight on how well each path worked in relation to other stakeholder visions.

CHAPTER IV

RESULTS

Composite Suitability Maps

As was to be expected, the various stakeholder visions yielded very different composite suitability maps. Looking at Figures 2 through 5, the economic and social visions appeared to be the most restrictive, or more limiting on the number of higher suitability values that were produced. The equal vision looked to be more forgiving than the aforementioned visions and the ecological vision appeared to be the most lenient. Taking a more critical look at the attribute tables illustrated in Tables 3 through 6, the true results materialized. These tables illustrate the total pixel count for each suitability class as well as the percentage each suitability value represents in the study area.

Table 3. Social vision suitability map attribute table

| Suitability Value | Count | Percent |
|---|---|---|
| 1 | 70,832,940 | 26.240768 |
| 2 | 134,547,788 | 49.844566 |
| 3 | 37,834,796 | 14.016276 |
| 4 | 22,852,676 | 8.4660020 |
| 5 | 3,644,309 | 1.3500710 |
| 6 | 218,081 | 0.0807900 |
| 7 | 4,120 | 0.0015260 |

The social vision was by far the most restrictive. This vision gave the majority of the weight to the land use diversity layer (0.52) which emphasized the degree of land use mixture. Higher degrees of land use mixture were concentrated around the more urban locations and along transportation routes. It also gave a significant weight to the urban intensity layer (0.27). The vision honed in on very urbanized areas characterized by both a high degree of land use mixture and high residential and/or employment densities. Not even 1.5% of the entire social vision map was categorized at suitability levels of 5 or higher. Barely 0.08% of the map received suitability values of 6 or higher and just over 0.0015% of the pixels received suitability values of 7. No pixels were classified in the highest suitability class (8).

Table 4. Economic vision suitability map attribute table

| Suitability Value | Count | Percent |
|---|---|---|
| **1** | 121,262,767 | 44.923000 |
| **2** | 118,985,885 | 44.079506 |
| **3** | 3,114,362 | 1.1537460 |
| **4** | 77,313 | 0.0286410 |
| **5** | 14,848,811 | 5.5008900 |
| **6** | 11,408,012 | 4.2262120 |
| **7** | 230,545 | 0.0854080 |
| **8** | 7,015 | 0.0025990 |

With regards to the economic vision, about 10% of all of the pixels were classified with suitability values of 5 or higher. Over 4% of the pixels fell into the suitability category of 6. This vision, along with the ecological vision, yielded the highest number of category 8 suitability pixels with a total count of 7,015. It also yielded some of the highest pixel counts in suitability categories 6 and 7 relative to the other visions. This vision still presumed to be very limiting as upwards of 90% of all the pixels fell into the suitability categories of 1 or 2. This vision heavily weighted the economic suitability layer (0.52) which produced an overall suitability map where high values were dictated by the existing transportation network. The vision also gave a significant weight to the urban intensity layer (0.27) which further restricted high suitability values to more highly urbanized areas.

Dealing with the equal vision, the vast majority of the pixels were characterized by lower suitability values, which is consistent with the other composite suitability maps. However, pixel counts in suitability categories 3 and 4 increased dramatically in relation to those observed with the economic vision. As with the economic vision, roughly 10% of all the pixels were classified with suitability values of 5 or higher.

The ecological vision proved to be the most lenient of all the four that were depicted. A dramatic shift to the top half of the suitability values was observed. Over 67% of all the pixels fell into suitability categories of 5 or higher. Relative to the other visions, the ecological vision contained the greatest number of pixels in the suitability classes of 6, 7 and 8. The map produced from this vision exhibited the least amount of variation in which over 90% of all the pixels were categorized as either very unsuitable (1) or mildly suitable (5). The ecological vision gave the majority of the weight to protect green space (0.52), but also gave a significant weight to the urban intensity layer (0.27).

Table 5. Equal vision suitability map attribute table

| Suitability Value | Count | Percent |
|---|---|---|
| **1** | 69,500,797 | 25.747261 |
| **2** | 18,600,082 | 6.8905850 |
| **3** | 118,747,209 | 43.991085 |
| **4** | 36,138,068 | 13.387707 |
| **5** | 21,012,935 | 7.7844510 |
| **6** | 5,782,106 | 2.1420390 |
| **7** | 151,630 | 0.0561730 |
| **8** | 1,883 | 0.0006980 |

Table 6. Ecological vision suitability map attribute table

| Suitability Value | Count | Percent |
|---|---|---|
| **1** | 86,341,523 | 31.986076 |
| **2** | 2,431,452 | 0.9007560 |
| **3** | 22,562 | 0.0083580 |
| **4** | 102 | 0.0000380 |
| **5** | 162,066,971 | 60.039322 |
| **6** | 18,646,563 | 6.9078050 |
| **7** | 418,522 | 0.1550460 |
| **8** | 7,015 | 0.0025990 |

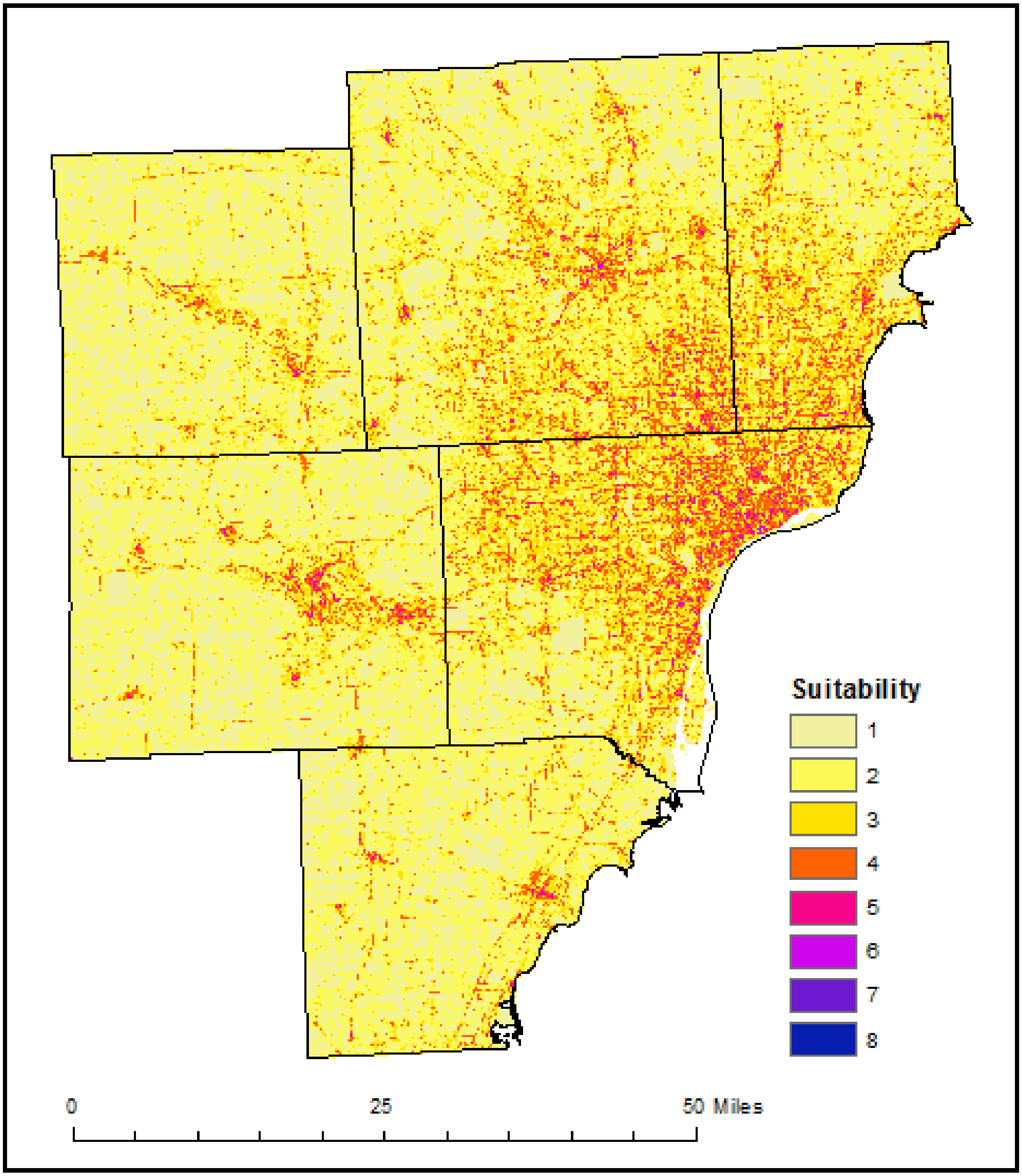


Figure 2. Social vision composite suitability map

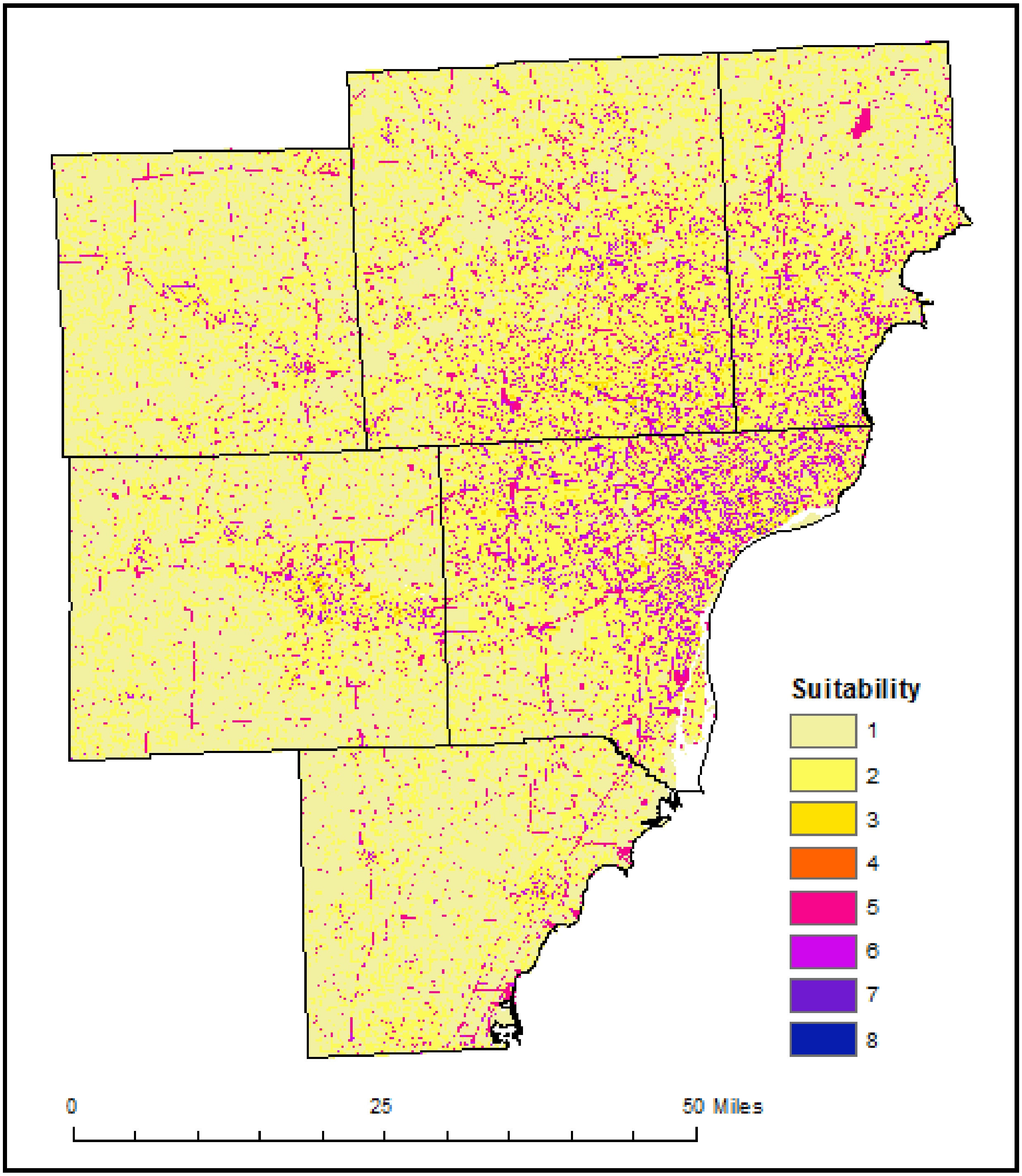


Figure 3.  Economic vision composite suitability map

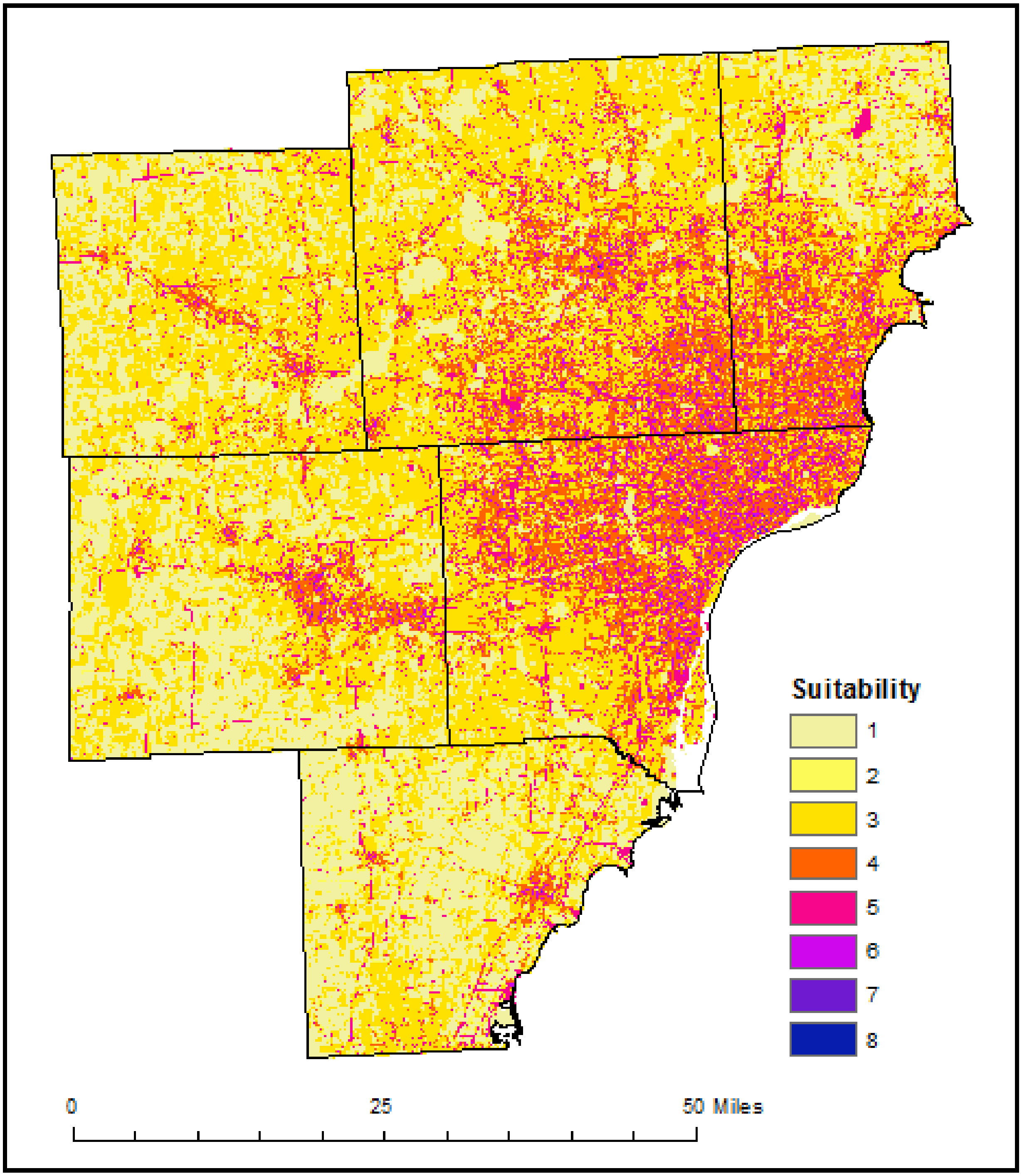


Figure 4. Equal vision composite suitability map

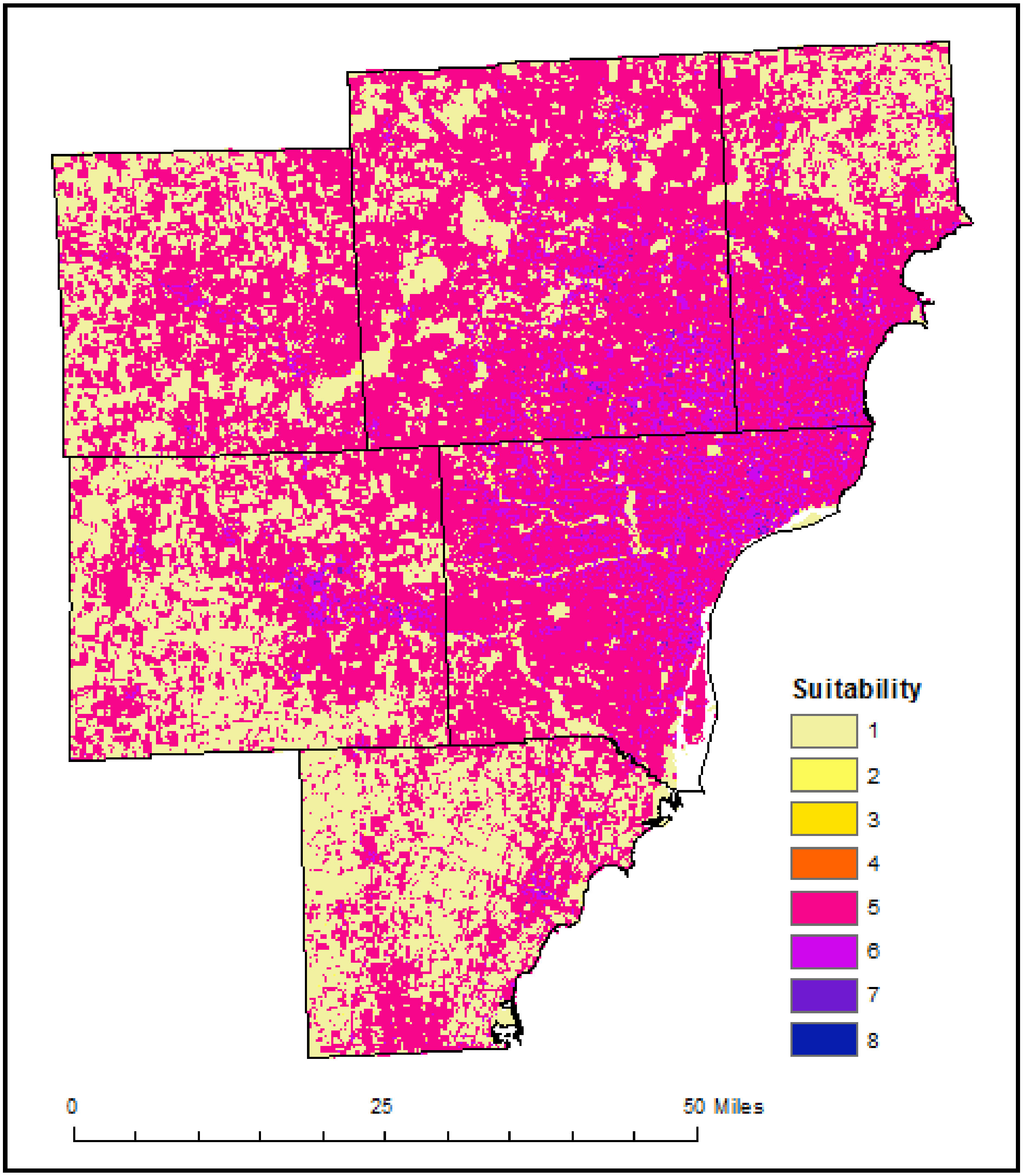


Figure 5. Ecological vision composite suitability map

Station Sites

The number of stations for the transit network was selected depending on the vision being portrayed. As shown in Figure 6, the ecological and economic visions had the same seven stations. A station was located within each of the following cities: Ann Arbor, Brighton, Center Line, Dearborn, Detroit, Lathrup Village, and Pontiac. Aside from Monroe County, all counties contained a station. Oakland and Wayne Counties had two stations each.

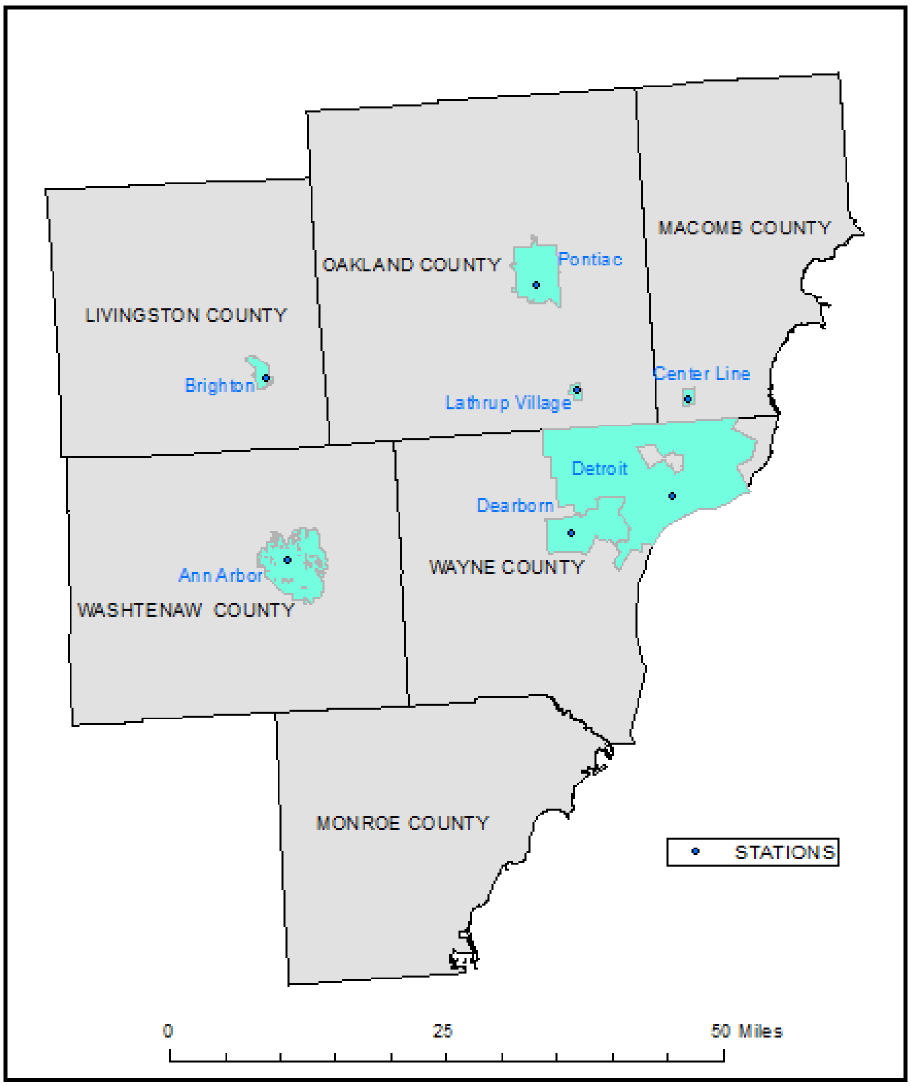


Figure 6. Station sites for the ecological and economic visions

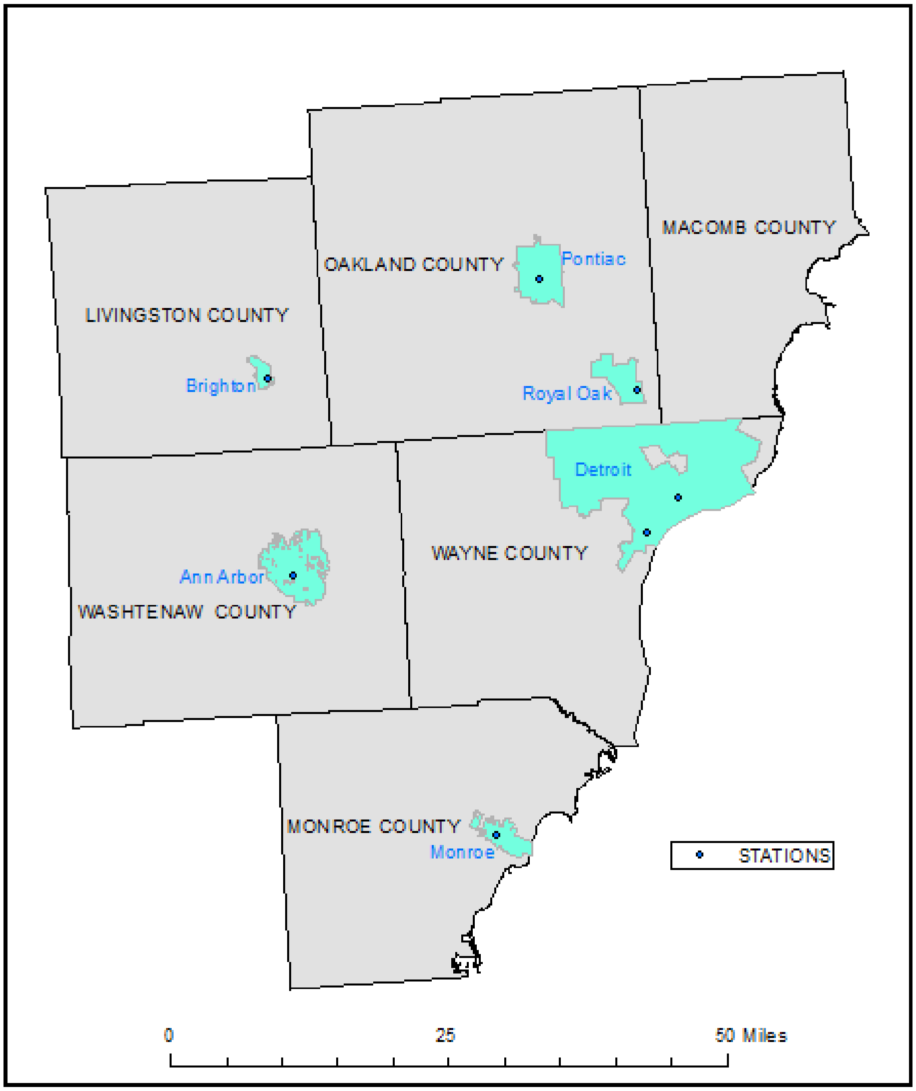


Figure 7. Station sites for the social vision

As can be seen from Figure 7, the social vision also derived seven stations which were located in Ann Arbor, Brighton, Detroit (2), Monroe, Pontiac, and Royal Oak. Figure 8 displays the station locations for the equal vision. This vision only returned five stations located in Ann Arbor, Brighton, Detroit (2), and Royal Oak. There were no stations located in either Macomb or Monroe County. All four visions contained similar station locations in Ann Arbor, Brighton, and Detroit. The ecological, economic, and social visions shared a common station in Pontiac.

The social and equal visions both placed a station in Royal Oak. The social vision also introduced a station in the City of Monroe while the ecological and economic visions placed new stations in Lathrup Village and Center Line.

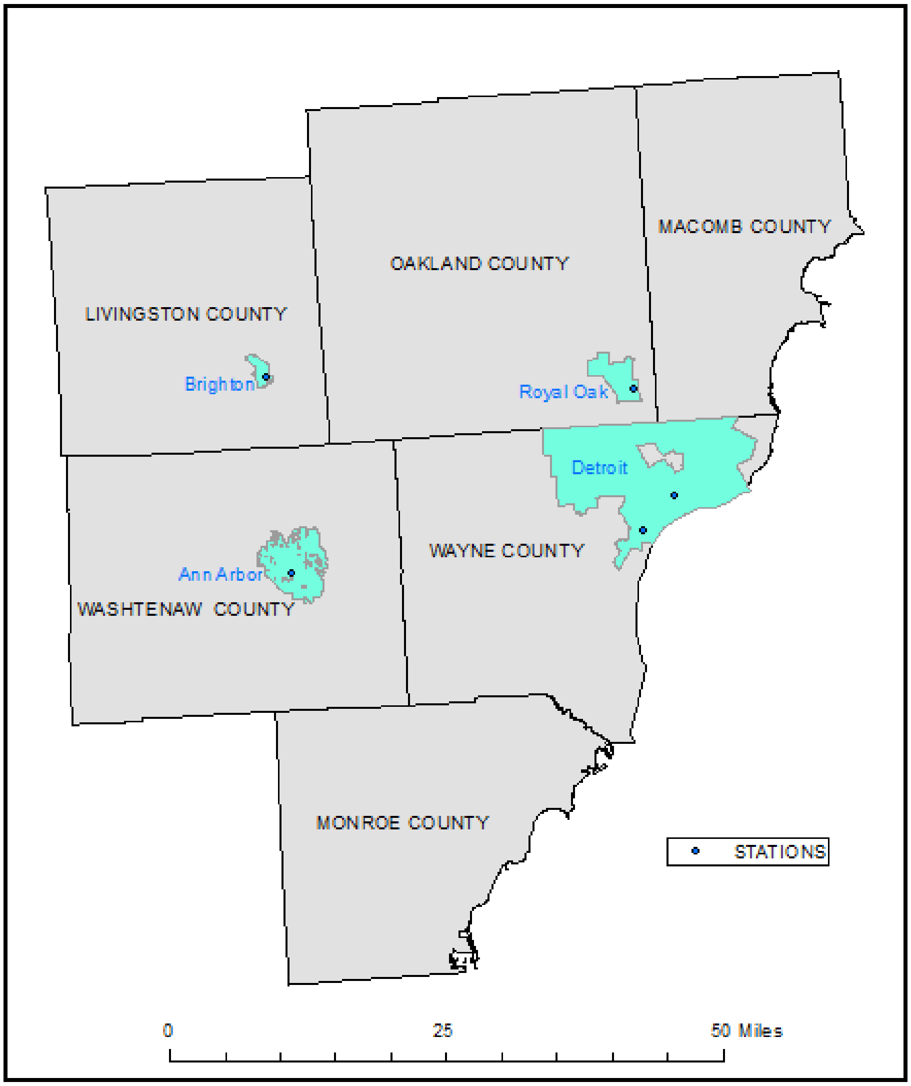


Figure 8. Station sites for the equal vision

## Corridor Sites

To a certain extent, the routes from all four visions followed the built transportation matrix. Besides some deviations to connect to the station sites, the proposed routes radiated out of the City of Detroit following the major road netork.  These major roads included Grand River Avenue, Woodward Avenue, I-94, I-75, and I-96/696.

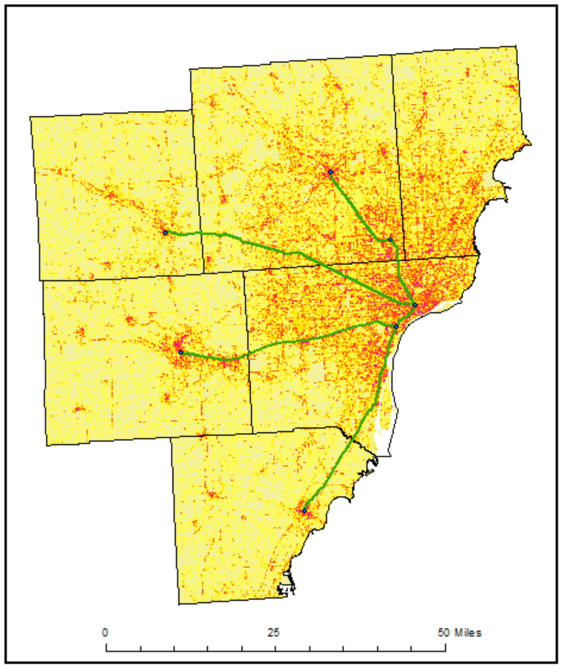


Figure 9.  Social vision transit route

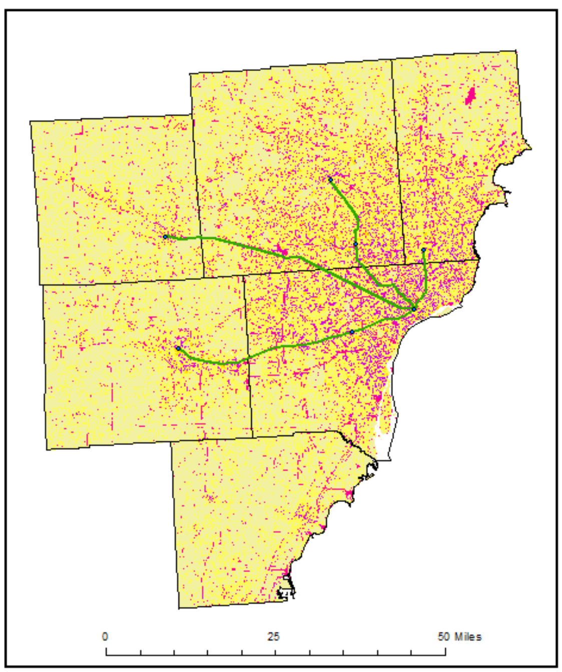


Figure 10.  Economic vision transit route

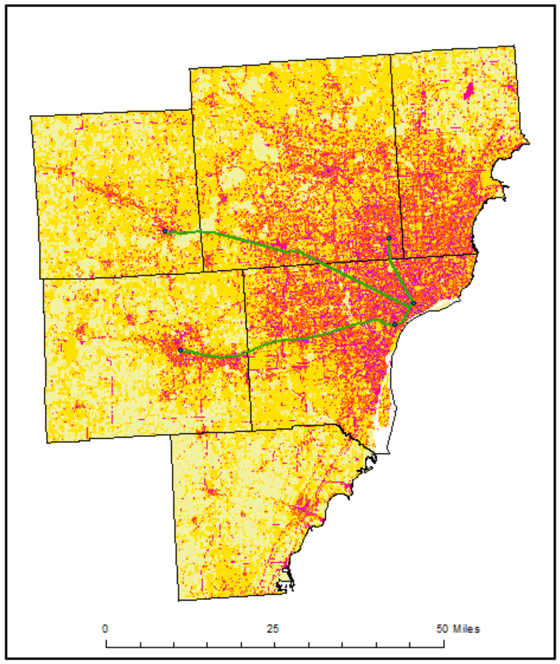


Figure 11. Equal vision transit route

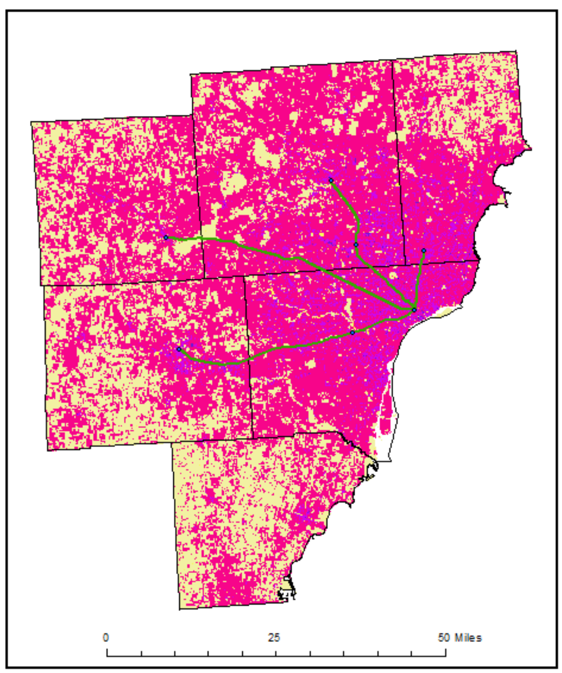


Figure 12. Ecological vision transit route

The length weighted mean (LWM) calculations yielded some interesting results. As a reminder, the LWM associated a cost or impedance value to each route in which lower impedance values were viewed as less costly and more suitable. In this study, the underlying cost raster grids used in the LWM calculations contained values ranging from 1 to 8. Thus, the derived length weighted means inherited this same range. The first LWM calculation for each route was carried out using its own cost raster layer. The cost raster layers of the three remaining visions were applied sequentially to derive three more LWMs for each route. A least cost path was generated for each vision based on that vision's cost raster. Inherently, each route received the lowest impedance value when LWMs were calculated using its corresponding cost raster relative to the remaining routes.

Table 7. Generated length weighted means for the transit routes

| | Social LWM | Economic LWM | Equal LWM | Ecological LWM |
|---|---|---|---|---|
| **Social Route** | **3.501581** | 3.422590 | 3.457922 | 3.162884 |
| **Economic Route** | 3.577977 | **3.077285** | 3.361560 | 3.034801 |
| **Equal Route** | 3.527369 | 3.184085 | **3.260968** | 3.096822 |
| **Ecological Route** | 3.807147 | 3.879599 | 3.752449 | **3.023890** |

Since the routes themselves were a function of the corresponding cost raster grids, comparing the impedance values of a single route across all four grids did not yield any significant findings. This was because the impedance values were derived from the underlying cost raster and each raster weighted the individual criterion layers differently. Thus, the values were not related and there was no logical basis for comparison. However, all four routes could be compared across a single cost raster.

As seen from Table 7, the generated impedance values ranged from 3.02389 to 3.879599, with the largest range within any route comparison being 0.802314. These results were very surprising as the suitability maps appeared to be very dissimilar. They also made interpretation of the LWMs difficult since no route significantly outperformed any other route. It was noted that the ecological route seemed to receive the highest associated cost value relative to every other cost raster but its own. The social route tended to produce higher LWM values relative to the cost raster grids of the other visions. The other routes produced no obvious trends.

To ease interpretation of the results, the derived impedance values were ranked relative to each cost raster. This gave an idea of which routes worked better in relation to all visions. Table 8 displays these ranked values. Of all four routes, those of the economic and equal visions received the lowest total when the ranked values were summed followed by the social and then the ecological route.

Table 8. Ranked impedance values

| | Social LWM | Economic LWM | Equal LWM | Ecological LWM | TOTAL |
|---|---|---|---|---|---|
| **Social Route** | 1 | 3 | 3 | 4 | 11 |
| **Economic Route** | 3 | 1 | 2 | 2 | 8 |
| **Equal Route** | 2 | 2 | 1 | 3 | 8 |
| **Ecological Route** | 4 | 4 | 4 | 1 | 13 |

# CHAPTER V

# DISCUSSION

Calculating the length weighted means for each route over each of the four cost raster layers allowed the routes to be analyzed and compared. By definition, each cost raster derived the route that was the least costly path. It was only logical that comparing all four routes over each raster separately yielded that the route derived from the raster in question outperformed the remaining three routes. As mentioned earlier, each route cannot be compared to itself across multiple cost rasters. Thus, the results of the LWM calculations were interpreted and compared by column in Table 7. As a reminder, the LWM calculations describe an average cost for each route in reference to the specified cost raster; the lower the result, the lower the associated cost and the more suitable the route.

The range between the LWM values for the social, economic, equal, and ecological visions were 0.31, 0.80, 0.49, and 0.14, respectively. Thus, the variation between the four routes was slim. The possible values ranged from one to eight. Since all LWM values were between three and four, which ultimately corresponded to a suitability value of about six, each of the four routes were fairly suitable with respect to all the stakeholder visions. In reference to Table 8, the total column suggests that the economic and equal routes outperform the social and ecological routes but the variation of the actual LWM values suggests that any one of the proposed routes would suffice without overstepping the views of any one stakeholder. In essence, the study did not return a single optimal route. However, the planning process is a very political one and the GIS techniques used in study provided multiple options that could be used as a basis for delineating a single optimal route.

Employing different techniques or data sets could potentially improve and fine-tune the results in future studies. The study used number of jobs as an initial indicator of potential ridership and did not directly consider non-work travel. Also, a measure of zero car households could be incorporated to capture another group of potential riders. The inclusion of vacant or government-owned land could open further potential site locations and/or corridors. The specified station locations could also be further analyzed with respect to the minimum construction dimensions for transit stations and included parking areas. The methodology for deriving transit routes was to pinpoint station locations and then build routes between them. Another option would have been to derive the most suitable paths across the study area and place stations along these delineated routes.

# CHAPTER VI

# CONCLUSION

The derived transit routes for each vision proved to be very similar. This was most likely a factor of the criteria used. The economic theme restricted high suitability values to the transportation network. The land use diversity theme gave higher suitability scores to those areas with a higher degree of land use mixture. Areas of larger residential/employment densities contained greater suitability in the urban intensity theme. The environmental theme concentrated better suitability scores around more developed areas. Thus, all four layers focused the suitable locations around more urbanized areas which are characterized by a more extensive road network, higher employment and residential densities, more development, and greater land use mixture.

Looking back at the study, it was beneficial to quantify each route based on a length weighted mean. This allowed the different routes to be compared and analyzed. Although the range of these values proved to be very small, the results emphasized that the routes of the equal vision and the economic vision proved to better alternatives. Also, since the range of the LWM values was so small, an optimal route could potentially be chosen without deviating too far away from the ideals of any one stakeholder group.

A drawback of the study, as with many studies, was the use of surrogate data to represent certain objectives or criteria that would be used in a transit study such as this. Data can be used as a proxy to emulate certain ideas but surrogate data is not always perfect. Also, due to time constraints, criterion weights were used from Keshkamat's study in 2007. This potentially creates an issue as the data utilized in the current study was not exactly the data used in Keshkamat's study. If it was feasible, criterion weights specific to this study could have been derived through collaborations with regional experts. Most likely, the input from specialists and researchers from the Detroit metropolitan area would have provided different weight factors.

Although the study included some major themes, the list was not exhaustive. To add to the study in the future, additional factors should be included. These factors may consist of construction costs, minimum construction dimensions, slope restrictions, optimized distances between station sites, and the like. More criteria can always be included to fine-tune the results.

Overall, planning and implementation of rail transit system is a financially expensive and time consuming process in which many parties and factors are involved. Geographic information systems provide a platform for mapping and analyzing numerous factors to aid in the decision making process. This study solidified the fact that GIS-based land use suitability analysis can produce a strong foundation for transit planning.

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