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Geospatial Analysis of Smart Growth and Transit Oriented Developments

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GEOSPATIAL ANALYSIS OF

SMART GROWTH AND TRANSIT ORIENTED

DEVELOPMENTS

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Capstone Project

For

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ABSTRACT

Rapid population growth, water and air pollution, overloaded public services, and traffic congestion can stress economies and result in unsustainable communities. Geographic Information Science (GIS) is a valuable technology for reversing negative these types of trends by identifying areas that may presently exhibit Smart Growth characteristics. Rather than expand on the current transportation infrastructure and develop new Smart Growth communities, San Diego Metropolitan's Transit System (SDMTS) intends to use this study to review the current transit routing infrastructure in an effort to support communities exhibiting Smart Growth potential. Communities along existing transportation infrastructure will analyzed as potential Smart Growth and TOD communities. After the study is completed, SDMTS will have the geospatial data necessary for supporting future Smart Growth development.

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ACRONYMS AND ABBREVIATIONS

EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
LR	Light Rail
SDMTS	San Diego Metropolitan Transit System
GIS	Geographic Information Systems
GPS	Global Positioning System
MTS	Metropolitan Transit System
NHTSA	National Highway Traffic Safety Administration
NHGIS	National Historical Geographic Information System
SanDAG	San Diego Association of Governments
SANGIS	San Diego Geographic Information System
SD-LRT	San Diego Light Rail Trolley
TOD	Transit Oriented Development
TMU	Transit Mix Use
USDOT	U.S. Department of Transportation
UT Trax	Utah Transit Authority Transit Express
VA	Veterans Administration

INTRODUCTION

California's primary cities are infamous for heavy traffic congestion, but there are solutions to this growing issue. Effectively utilizing and applying Smart Growth and Transit-Oriented Development (TOD) principles to current and future public transportation routes may reduce traffic-congested areas (Abukhater and Walker 2010). Public transportation such as Light Rail (LR) has a positive economic impact on communities (Smart Growth America n.d.). Examining and planning efficient transportation frequencies for LR and bus service routes are helpful in supporting the development of Smart Growth communities. Once Smart Growth improvements are in place, these communities attract new businesses, which in turn, create more jobs, thereby leading to an increase in regional spending (Smart Growth America n.d.).

Smart Growth America, an organization dedicated to educating states and communities about Smart Growth and TOD, defines Smart Growth as "building urban, suburban, and rural communities with housing and transportation choices near jobs, shops, and schools." The intended principle of Smart Growth is to have a positive environmental impact on local communities by reducing pollution and the costs related to private transportation, such as road repairs. (Smart Growth America n.d.). Walkability and public transportation will also reduce the number of serious accidents (Victoria Transportation Policy Institute 2014). The common goal

of Smart Growth and TOD initiatives are to provide a safer, cleaner, and more affordable environment (Smart Growth America n.d.). Smart Growth and TOD communities provide commuters with more public transportation options, thus increasing ridership. Moreover, increasing easy public transportation access reduces traffic and traffic congestion, resulting in less spending on road maintenance (Smart Growth America n.d.).

Several factors are required for classifying potential Smart Growth communities near transportation infrastructures. These factors include access to safe and complete streets, sidewalks, bike routes, and pinpointing businesses within walking distance of community housing. According to The Smart Growth Network, some of the important principles that guide Smart Growth and increase ridership include:

1. Mixed land use.

2. Building and utilizing compact structures.

3. Support and create walkability.

4. Provide transportation choices.

(The Smart Growth Network 2006).

GIS technology is an ideal tool when analyzing potential Smart Growth and TOD developments in existing urban zones. An effective GIS analysis provides developers and transportation planners with data needed to identify potential candidate communities for a Smart Growth development. Educating potential communities about the advantages of Smart Growth's incentives such as reducing traffic congestion, economy improvement, and optional

commuter choices may encourage communities to welcome Smart Growth development (Smart Growth America n.d.).

PROBLEM STATEMENT

San Diego currently has a well-established transportation infrastructure. The San Diego Metropolitan Transit System (SDMTS) is looking towards the future of commuter ridership through the development of Smart Growth and TOD communities. An example, such as the increase in TOD around Denver, and Colorado's development of its FasTracks with a TOD focus, reinforces the ability to reshape land use development (Ratner and Goetz 2013). The San Diego Association of Governments (SanDAG) conducted a study and identified future Smart Growth and TOD developments that would be located on new public transportation infrastructures. San Diego's existing transit systems, however, were not included in the study or expanded on to identify existing communities that could benefit from the transportation infrastructure already in place. Some potential Smart Growth communities already contain Smart Growth and TOD characteristics that could be further developed and supported by existing transportation infrastructure through planning. Additionally, preplanning developments near current transportation routes will also prevent building in areas that do not support public transportation needs.

The Veterans Administration (VA) in San Diego became the latest example of transportation and land use planning oversight. The VA established a new medical center with the promise that veterans would have

better access to medical care. The medical center had one major drawback, when planners selected the new location; access to public transportation was not considered in the planning. As a result, older veterans and veterans with disabilities now have a difficult time commuting due to the location of the nearest public transportation stop one half mile downhill from the VA medical center (Hoffman 2014). Working with the current public transportation infrastructure will prevent these types of development mistakes.

This study will use GIS spatial analysis technology to identify potential Smart Growth/TOD areas around the current SDMTS transportation infrastructure.

GOALS AND OBJECTIVES

The goal of this project is to conduct an independent spatial analysis of demographic and physical variables needed for targeting Smart Growth and TOD areas around downtown San Diego's current SDMTS routes. The City of San Diego had previously conducted a study identifying future Smart Growth Communities and designing proposed transit routes to support those communities. Analysis of potential Smart Growth areas along the current transit system was not part of the study. This analysis will expand on SanDAG's study by analyzing the existing transit system in downtown San Diego using population demographics, frequency of transit stops, availability of lighting at transit stops, employment demographics, bike routes as analysis for walkability, mixed land use, and car ownership. A calculation of

the variables using raster spatial analysis will identify potential Smart

Growth/TOD communities located near existing public transportation routes.

SIGNIFICANCE

The significance of this project is to classify potential Smart Growth

areas around already existing transit routes SDMTS. An ideal and sustainable

Smart Growth environment would include analysis of crucial variables and

amenities such as mixed land use, demographics, safe access to transit

stops and transit stop amenities. The results of this study will assist SDMTS

in adjusting its current transit system to fit the needs of the targeted Smart

Growth communities, and ultimately aid in reducing dependency on private

vehicles. The byproduct of using GIS study data could help generate

increased public transportation ridership, relieve traffic congestion on San

Diego's roads and freeways, encourage, and promote the development of

walkability, and expand residential access to local businesses, employment,

and public transportation.

LITERATURE REVIEW

Gradual Rasterization: Redefining the Spatial Resolution in Transport Modeling

Selecting the right model for transportation analysis can be difficult,

and focusing only on zoning may produce inconsistent results. Using raster

spatial units rather than zones allows for assigning different weights to

variables and calculating individual cell values (Moeckel and Donnelly 2014)**.**

Moreover, it makes it possible to use spatial analysis to combine several

layers of data by calculating all the layers together. The raster cell method is commonly used to analyze urban data. Another issue with analyzing zones instead of cells is that zones tend to change over time, older data may not complement newer data, and the data may change. Moreover, zonal analysis is subject to the Modifiable Areal Unit Problem (MAUP), in which results of the analyses can be very different depending on the scale and resolution of areal units. A heavily populated area may become less populated depending on how zones are altered. Compared to other methods of cell calculations, including zone calculation, raster cell calculations are more reliable and provide better analysis (Moeckel and Donnelly 2014).

The Need for Mixed Land Use Planning

Planning land use without considering existing public transportation infrastructures in the early stages of community development can negatively influence commuter behavior. The VA spent months planning a new clinic that would serve local Veterans by providing better health care to replace an existing VA medical clinic (Hoffman 2014). After the VA opened the new clinic to the public, the lack of transit oriented planning was immediately evident. Veterans who had relied on public transportation to reach the old VA medical clinic soon discovered that access to the new clinic was problematic. They had no difficulty accessing the prior clinic via trolley and/or bus. The Coaster train was now the only public transportation available to the new clinic. The Coaster's nearest stop required a one-half mile walk to and from the clinic. For some Veterans, especially those with

disabilities, it is now difficult to reach the clinic due to the distance and the fact the clinic is located uphill from the Coaster's nearest station (Hoffman 2014).

Combining Smart Growth and TOD

Smart Growth and TOD is a combination that should never be ignored. Utilizing tools to help identify potential communities that would benefit from Smart Growth makes economic sense. Denver's Transit Mixed Use (TMU) 20 project is using Smart Growth principles to create a mixed-use district in an area that is currently underutilized (Tucker, et al. 2008). The project will support existing offices, retail establishments, apartments, and hotels using a LR system that Denver officials hope will increase ridership to these areas (Tucker, et al. 2008). This is an example of effective use of Smart Growth/TOD principles.

The Reshaping of Land Use and Urban Form in Denver through Transit – Oriented Development

Denver, Colorado has experienced changes in the development of the FasTracks TOD and land use program. TOD affected the downtown areas of Denver and its influence decreased by distance from the downtown area. As mixed land use increased, so did population density around specific stations. Areas farther away from downtown Denver Urban Neighborhood stations only experienced minor mixed land use changes and the population density remained typical of similar neighborhoods that are not TOD. For the future reshaping of Denver, careful planning has been placed on future stations by

incorporating TOD initiatives and building transit stations with the purpose of supporting TOD (Ratner and Goetz 2013).

Smart Growth = Smart Cities

George Washington University directed a study of urban areas that ranked America's Largest Metros by their walkability. Surprisingly, San Diego was ranked on the lowest scale as a "Level 4: Low Walkable Urbanism" (Leinberger and Lynch 2014). According to the study, San Diego is predominately drivable and less walkable when compared to Metros such as Washington, D.C., and New York, which were ranked as highly walkable.

George Washington University noted an interesting correlation between the average educational level and wealth when comparing walkable cities to the cities ranked at a lower walkability level. Cities with higher walkability rankings tended to have higher educational averages when compared to the lower walkability cities (Leinberger and Lynch 2014).

Economic Advantage

Balancing the transportation system with public access needs may contribute to increasing future development in areas that would otherwise not be easily accessible. Smart Growth planning with the goal of providing public transportation access to areas that are already developed, and making public transportation available to future developments can increase the value of the local economy (Ewing, Pedestrian and Transit -Friendly Design: A Primer for Smart Growth n.d.).

The Making of a Commuter

One proven method of attracting new transit riders is a well-planned transit system. Correlating transit times and stop frequencies to match rush hours and events, such as sporting events that typically leads to an increase in road traffic, will attract riders that find the public transit system a superior alternative to personal vehicles and traffic issues (Cervero 2008). Non-public transportation commuters may also be inclined to take public transportation if the costs of parking private vehicles increase. Planning public transportation necessities and discouraging private vehicle use in areas that have a high number of employees is beneficial in increasing ridership (Cervero 2008).

Federal Funding for TOD

Justification for federal funding for transit systems has evolved from "ridership, efficiency, and energy savings" to include TODs. TODs are shown to have a positive effect on local property values (Arrington n.d.). In some communities that have adopted TOD policies, land value has increased up to 50% (Arrington n.d.). The typical TOD community can expect an increase in revenue due to an increase in ridership. Walkability can also influence the economic advantages of TOD. Safe access to transit stops through walkability can make or break the appeal for using public transportation (Arrington n.d.).

TOD Development for a Rapid Generation

Developing a rapid transit system that appeals to the next generation is an essential in attracting new customers. A number of considerations should be included in the planning of future transportation infrastructures. Reducing time traveling long distances might attract new commuters by developing bus rapid transit (BRT) lanes on expressways allowing buses to get from point A to point B in a shorter amount of time (Ferris 2011). It is possible to determine increasing or decreasing the number of stations and the frequency of stops per line by evaluating population density surrounding transportation routes. Another method reducing the amount of time spent commuting would be increasing the span between stops and increasing the frequency of stops for select transit lines during rush hours (Ferris 2011).

Re-planning Transportation Success

Before 1990, Utah utilized a vast bus system that effectively supported public transportation commuters throughout the Salt Lake valley, but as time progressed, the city's population outgrew the transportation system (Envision Utah n.d.). State officials concluded that the average commute to work was 25 to 29 miles each way, and realized that as the population increased, the average time commuting also increasing. This resulted in additional stress on roads and increased pollution. As a solution, the Utah Transit Authority (UTA Trax) built a north/south transit express system along the city center, which eventually expanded into cities farther south (Envision Utah n.d.). Commuters can drive or take a bus to the center of the city, park

in convenient lots and ride public transportation to work. Utah is now looking towards the future in evaluating potential TOD communities that have or will include mixed land use, better bicycle, and walking routes, and attract employment, shopping centers, and other facilities further reducing commuting time (Envision Utah n.d.).

California Recognizes TOD Benefits

A 2002 study conducted by the California Department of Transportation defined Transit-Oriented Development (TOD) as a: "moderate to higher-density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use." (Parker, et al. 2002). Using its definition of TOD, California recognized the importance of redevelopment in transit planning.

The State realized that it must overcome obstacles during redevelopment including possible inadequate transit systems currently in place and reevaluating station placement to better serve the community (Parker, et al. 2002). Zoning issues and high costs can also hamper TOD projects from the start. To meet these challenges, California has offered strategies to encourage TOD development including comparing environmental concerns with zoning codes, the sale, and use of state land,

providing assistance, and advancing funds for the planning and development stages (Parker, et al. 2002).

The Typical Commuter

Dr. Robert Cervero conducted a study identifying the characteristics of the typical commuter. His observation included one-quarter mile distance from a rail station containing 6500 housing units, and concluded that TOD residents were more likely to work downtown and in areas that are transit accessible (Cervero 2008). He also discovered that average commuters are single, retired, childless, professional, and have emigrated to the U.S. from another country. Surprisingly, whether or not the average commuter owned a vehicle was not based on their residential location near a transit stop. He found that regardless of vehicle ownership, public transit commuters are leaving their vehicles at home and making the choice to take public transportation (Cervero 2008).

DESIGN AND IMPLEMENTATION

This study was conducted specifically for the San Diego Metropolitan Transit System (SDMTS) with the assistance of SDMTS manger, Don Varely. As the client, SDMTS requested that the study focus on the current transportation infrastructure located within 14.77 square miles of the downtown area of San Diego, California. SDMTS provided the majority of the demographic data used for analysis. In order to accomplish the analysis of potential Smart Growth and TOD locations, several data resources were used which included:

Primary Data Resources

- Demographic data: the National Historical Geographic Information System, SDMTS, and SanDAG provided Population, employment, income, and vehicle ownership statistics.

- Transit Data: The Metropolitan Transit System provided its own transit data. The data included the amount of service (measured in frequencies of per hour or per day) provided at each transportation stop.

- Land Use Data: Land use data were created by and downloaded from the SanDAG.

- Tiger/Line Shape files: The Census Block demographic tables used for the San Diego area were joined with Tiger/Line Shape files downloaded from the U.S. Census Bureau (United States Census Bureau 2014).

Secondary Data Resources

- Walkability of Neighborhood: No walkability scores exist for individual blocks or sidewalks in downtown San Diego; therefore, SanDAG bike lane data were used.

- Amenities Data: SDMTS provided its own transit amenities data for the study, which included commuters' access to lighting, maps, benches, and shelters.

Data Analysis

- Demographic Data: Population and employment densities were analyzed with higher densities being identified as a better identifier for TOD.

- <u>Analysis of Existing Transit Service and Stop Data</u>: Measuring distances from bus stops, the frequency of service (in frequency per hour or per day) provided at individual stops. Frequency of service was quantified with the highest frequency being most desirable. Due to the importance and popularity of LR, it was weighted by multiplying the existing frequency variables by three (f x 3).

- <u>Analyze Land Use Data</u>: Areas within downtown San Diego were weighted by the importance of the structure in Smart Growth development. SDMTS' requested that the study focused on residential and office locations. Urban neighborhoods that included multi-family residents were weighted higher than single-family residents. Offices building five stories or taller were weighted higher than smaller buildings. Resulting analysis were added to the final raster cell calculations to identify high-density residential communities near commercial and retail structures.

- <u>Walkability of neighborhood</u>: Due to the lack of walkability data for the area studied, bike lane data provided by SanDAG were used as a substitute. The buffering identified walkability at 500, 1000, and 1500 buffer zones. The individual distances were quantified at 500 = 5, 1000 = 3, and 1500 =1.

- <u>Stop amenities</u>: Lighting amenities were analyzed at individual bus stops and SD-LRT stations, and then quantified according to its effectiveness and availability. Other amenities such as benches, shelters, and maps were also analyzed for additional data analysis.

Tools Used for Spatial Analysis

Collected data were analyzed using the ArcGIS 10.2 software developed by the Environmental Systems Research Institute (ESRI). To represent a small section of downtown San Diego, block census data were used for demographic analysis due to it being the smallest geographic area used to tabulate decennial data (United States Census Bureau 2014). Tools used also included:

Joining feature class point data to Tiger/Line shape files and populated through ArcGIS "Symbology" features. The output represented quantitative values in an ordinal numeric and color ranking structure. All classifications were set at five individual classes using the Natural Breaks (Jenks) method.

Bicycle route line data were buffered at the distances of 500, 1000, and 1500 as requested by SDMTS.

Raster maps were created by using the "Polygon to Raster" or "Point to Raster" tools, the data were converted into a cell size of .001.

The quantitative results were further analyzed using the Spatial Analysis Tool –"Reclassify" and the variables were weighted by individual numerical rankings from one through five, with five representing the most desirable results, and variables quantified at one were the least desirable.

Once all the separate variables contributing to the identification of Smart Growth areas were processed through reclassification, the raster data were consolidated and calculated using the Map Algebra Tool and then analyzed with the Raster Statistics Tool.

Challenges

The timeframe for this project was a predicted complication that had to be overcome once the project began. Data that include San Diego's current walkability scores are still in development. If time constraints had not become a concern, walkability table datasets could have been created for this analysis. The walkability of the areas analyzed includes biking paths that could be used by both pedestrians and bicyclists.

SDMTS maintains current transit schedules, amenities and routes, while the other data sets were collected from other sources, however road conditions and present and future construction in the downtown area may interfere with accuracy of the implementation of data results. Current construction in San Diego has altered roads, and eliminated roads and sidewalks rendered some data obsolete. The most up to date data used for this study may not reflect these changes. Moreover, construction and unforeseen obstacles may interfere with the accuracy of the data.

Map Model

The model selected for this study is diagramed in Figure 1. The selection of the primary data model was influenced by Rolf Moeckel's research study, which found that spatial analysis is an ideal model for analyzing the layers required to calculate transportation and demographic data (Moeckel and Donnelly 2014). In the resulting data analysis, four map types were produced reflecting the data type used. The output point, gradual, reclassified, and vector maps were converted to raster format.
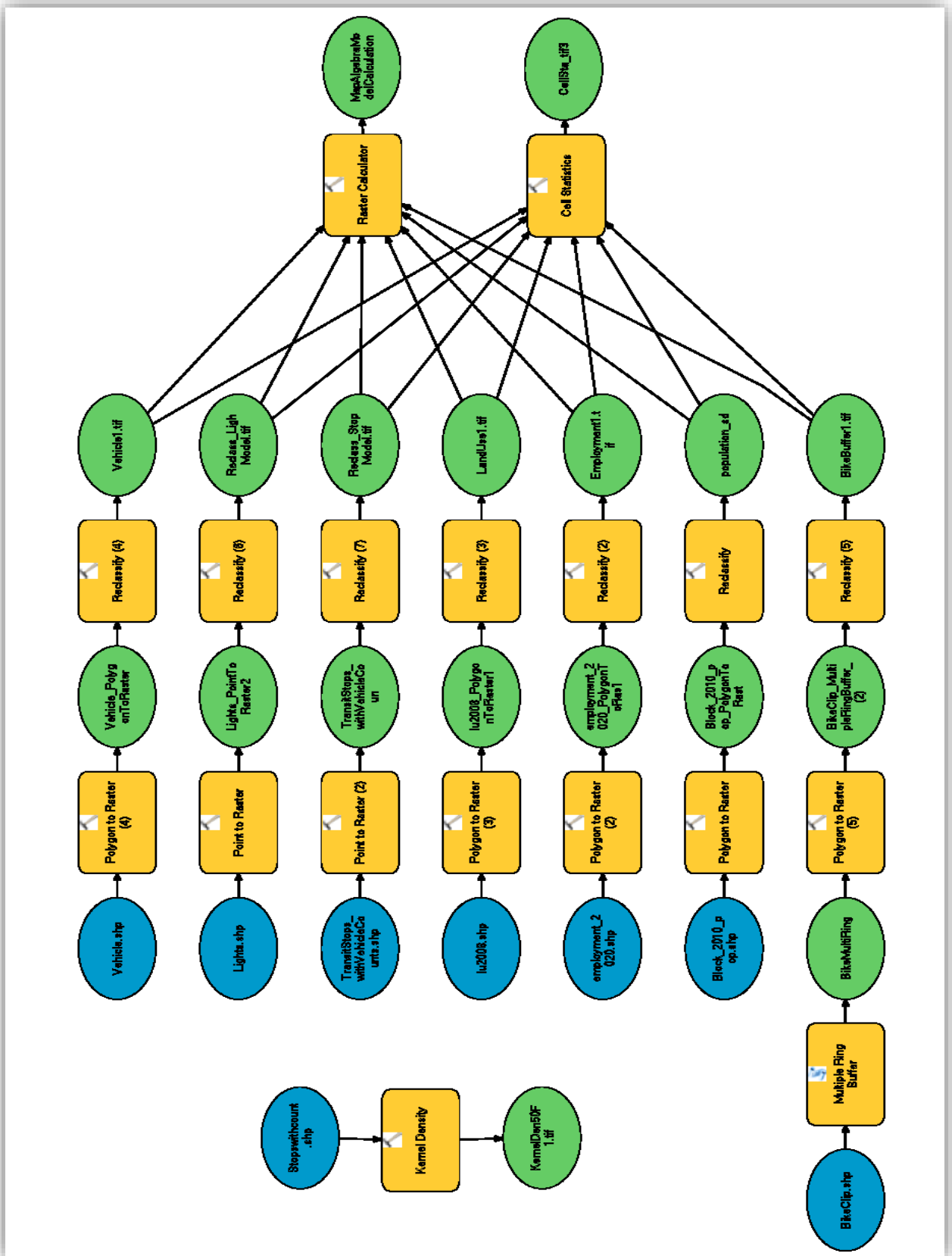
Figure 1: Raster and Kernel Density Model

During the process, data were funneled into a uniformed output using Natural Breaks (Jenks) as the classification for all map intervals. Because the area of study was limited to an area of approximately 14.77 square miles, the data were converted to raster using cell values of .001 by .001 for each of the individual layers.

The individual attributes within the raster data were assigned a weighted value established by SDMTS between one and five. The analytical process was finalized using map algebra to tabulate the quantified raster data into one consolidated map. Cell Statistics were also used as a cross reference. Based on all the data presented and map calculations, the final map could be used by SDMTS to identify areas for possible development of Smart Growth communities.

RESULTS

The goal of the study was to provide SDMTS with detailed maps and final analysis of the downtown area based on San Diego's SDMTS current routes. The study's GIS maps and data analysis were designed to assist SDMTS experts in making future TOD and Smart Growth decisions in identifying, creating, and supporting sustainable transit communities. The analysis from this project will be used by SDMTS for making current routing and stop alternatives and will be applied to future studies.

Maps were created for each set of data including: demographic, amenity, and bus and San Diego Light Rail Trolley (SDLRT) stop frequencies used in the study. Features including SDMTS Routes, transit stops, main

roads, and bike routes were added as additional map analysis and as an aid for comparing data within the different sets of maps.

Demographic Data

Population Data

Population data were analyzed at the census block level. The process included converting the vector data into raster and reclassifying the variables for the final analysis. The data in Figure 2 shows higher population densities around the current SDMTS routing system and in the city's center.

Smart Growth communities are able to support and accommodate increasing populations through mixed land use development and transportation options. Adding transportation options that supports land use development and provides easy access to transportation stops in densely populated areas may attract transit riders (Ratner and Goetz 2013). If the goal were to increase ridership, identifying densely populated areas would be crucial in reevaluation of the current routing schedules.

Identifying potential Smart Growth areas along the current transportation infrastructure essentially allows the city to prepare for an inevitable growth in population using Smart Growth planning. Creating transportation options may also reverse the undesirable side effects that large populations and population sprawl has on communities.

Adding a number of residential, commercial and transportation options will lower dependence on private vehicles. This could result in less stress on community roads and public services. A "higher quality of life" is the

ultimate objective of Smart Growth and TOD communities (Vermont Natural Resources Council 2014).

Downtown San Diego's 2010 population for the 14.77 square mile area observed is approximately 57,454 and population density per square mile totaled 3,890 (2014).

Population data, along with transportation and employment data, were one of the main datasets essential for this study. Measurements of block-level population densities in Table 1 were reclassified into a new weighted value scale from one through five. Populations between 0-52 people per square mile received a weight value of one, 53-184 people per square mile received a weighted value of two, 185-535 people per square mile received a weighted value of three, 536-2361 people per square mile received a weighted value of four, and 2362-5785 people per square mile received a weighted value of five. In this study, high population density is an important characteristic for determining potential Smart Growth communities.

Table 1: Population Re-Class Values (Raster Cell Size .001/Area 14.77 Square Miles)
Total Population Observed – 57,454
Units of People per square mile - 3890

Total Population 3,095,313	Weighted Unit Values	Raster Cell Counts
0-52 People per square mile	1 (Red)	902,143
53-184 People per square mile	2 (Orange)	104269
185-535 People per square mile	3 (Yellow)	33735
536-2361 People per square mile	4 (Light Green)	17647
2362-5785 People per square mile	5 (Green)	1584
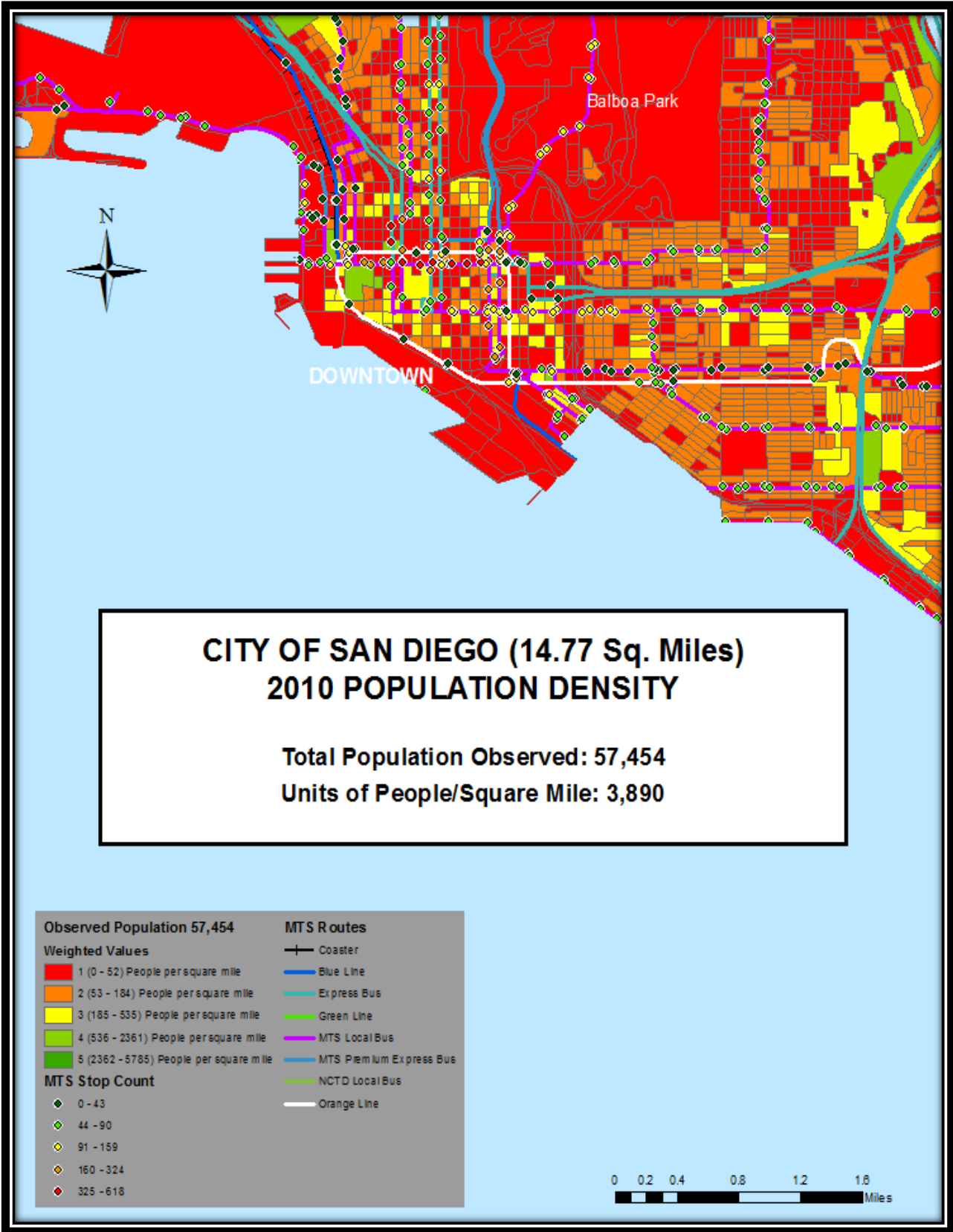
Figure 2: Population Density Map (Map Created by Michelle Nichols; Data received from the San Diego Metropolitan Transit System [SDMTS])

Vehicle Ownership

A study conducted by the University of Utah concluded that members of Smart Growth communities reduced their dependence on private transportation and were more likely to utilize public transportation (Litman 2014).

Public transportation can increase opportunities for low-income families and commuters that work in downtown San Diego. Some of the methods recommended by the Metropolitan Transportation Commission's 2007 report for reducing the amount of vehicles include:

1.   Incentive programs encouraging public transportation: Once potential Smart Growth areas are identified improvements to get safely to and from transit stops and lower fares will reduce the economic impact on families.

2.   Limiting the amount of parking: By limiting the amount of parking and applying parking maximums, public transportation becomes more convenient.

3.   Increase parking fees: Traveling to the downtown area from the outer area could offset the costs of parking. If parking is harder to find in the city and parking lots are provided at transit stations, the convenience and cost effectiveness of taking public transportation will increase.

4.   Up to date parking payment technology at park-and-ride

lots: Making paying for parking at park-and-ride lots easier is a solution to

generating revenue for transit systems.

5.   Using revenue from parking to support the local area:

Using the revenue from parking management towards improvements in both

the local community and transit stop upkeep would add to the appeal of

taking public transportation.

(Metropolitan Transportation Commission 2007)

When comparing the vehicle ownership map in Figure 3 to the income

map in Figure 4, populations living in areas that have a higher density of

households with an annual income of $30,000 or less appear to own fewer

personal vehicles. The downtown area is weighted as having moderate to

low vehicle ownership.

In Table 2, the vehicle variables were re-classified to one through five

weighted measurements with the lower cell value input of one for higher

vehicle density and highest cell value of input of five for lower vehicle

density resulting in identifying lower vehicle density as ideal for potential

Smart Growth communities.

Table 2: Vehicle Re Class Values (Raster Cell Size .001/Area 14.77 Square Miles)
Total Vehicles Observed - 46,372
Vehicles Per Square Mile – 3,140

Values	Weighted Unit Values	Raster Cell Counts
0-281	1 (Green)	656,508
282-532	2 (Light Green)	1,525,588
533-835	3 (Yellow)	5,434,683
836-1395	4 (Orange)	1,304,706
1396-2612	5 (Red)	2,095,275

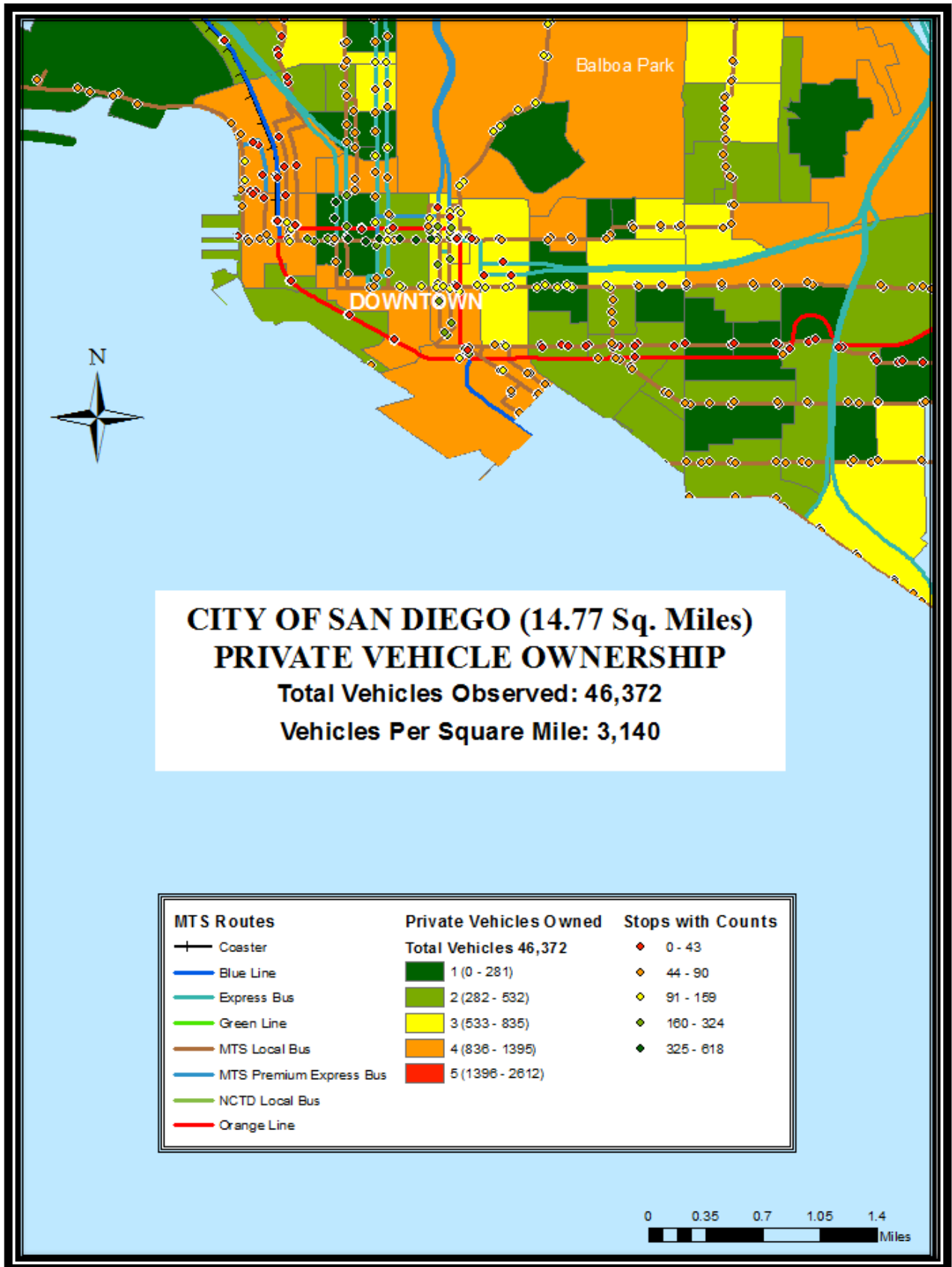**Figure 3: Vehicle Ownership Density Map (Created By Michelle Nichols: Data Provided By San Diego Metropolitan Transit System [SDMTS])**

Income Data

SDMTS is interested in developing ridership alternatives in areas where household yearly income levels are at or below $30,000 per year. The average family spends over fifty percent of the family's income on housing and transportation *(Smart Growth America n.d.).* Low-income family data are important in identifying Smart Growth locations. Families in these areas would benefit from affordable transportation options and better living environments. Developing Smart Growth transportation opportunities that reach low-income areas will provide access to jobs and valued services (U.S. Environmental Protection Agency 2013)*.*

San Diego's cost of living was ranked by Kiplinger's as the tenth highest in the United States at 30% above the national average (Rapacon 2014)*.* Household incomes less than $30,000 are far below San Diego's reported household median income of $64,000 (Rapacon 2014)*.*

The low-income densities are observed in the central, eastern, and southern portions of the income map where population density is higher (Figure 4). Table 3 shows the reclassification from category values to weighted values with the lower income density areas (Green) representing potential Smart Growth areas.

Table 3: Low Income Households< 30K (Raster Cell Size .001/Area 14.77 Square Miles)
Total Household Density: 15,194
Households Under 30k Per Square mile: 1,029

Values	Weighted Unit Values	Raster Cell Counts
0-83	1 (Red)	525,588
84-104	2 (Orange)	634,683
105-274	3 (Yellow)	304,706
276-486	4 (Light Green)	95,275
487-1589	5 (Green)	608

CITY OF SAN DIEGO (14.77 Sq. Miles)
HOUSEHOLDS OBSERVED WITH
INCOME UNDER $30,000
Total Households Observed: 15,194
Households Under 30k Per Square Mile: 1,029

Households Under 30k
Households Observed: 15,194

1 (0 - 79)
2 (80 - 178)
3 (179 - 284)
4 (285 - 472)
5 (473 - 1012)

Stops with Counts
0 - 43
44 - 90
91 - 159
160 - 324
325 - 618

MTS Routes
Coaster
Blue Line
Express Bus
Green Line
MTS Local Bus
MTS Premium Express Bus
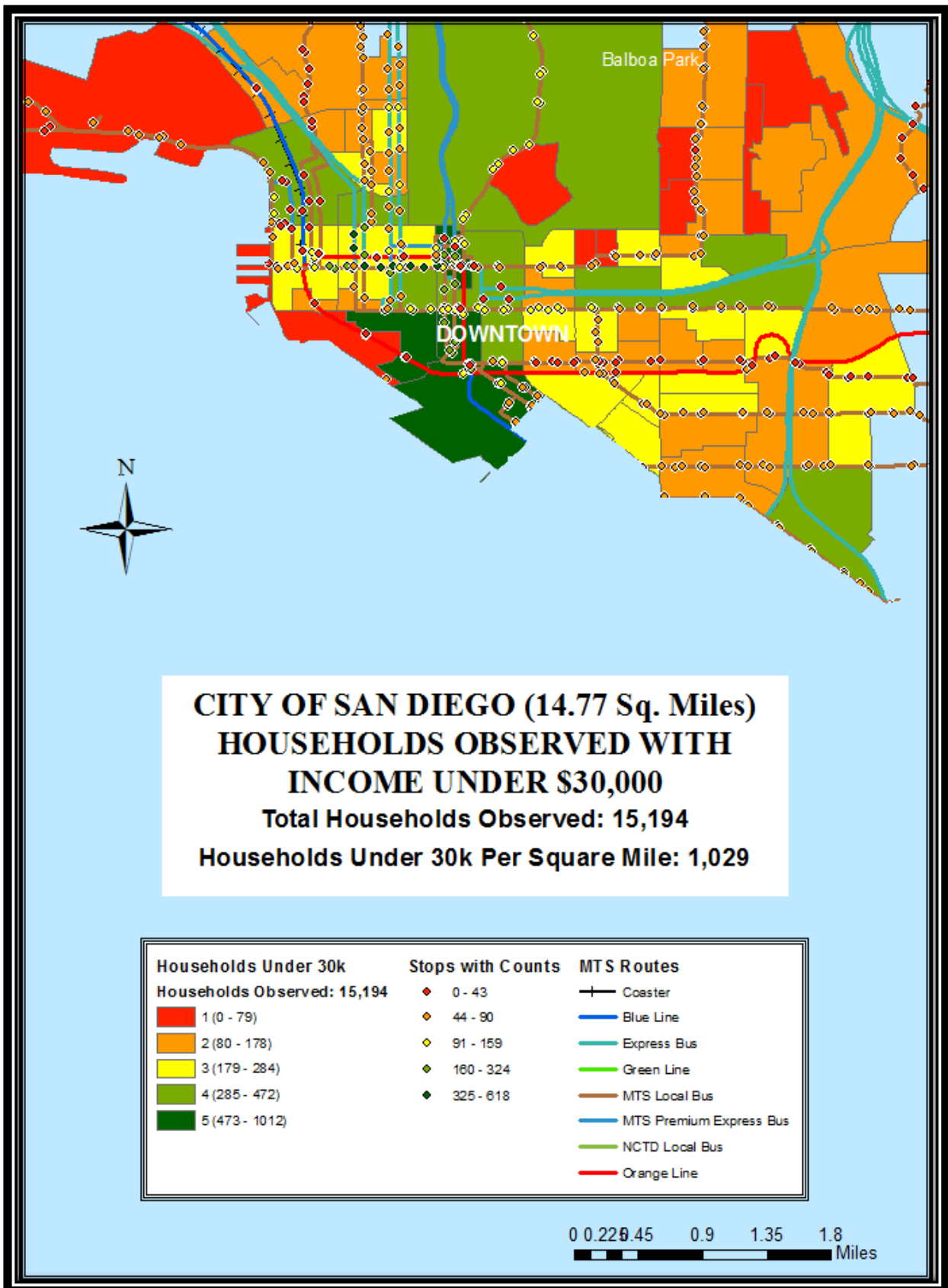NCTD Local Bus
Orange Line

0 0.225 0.45 0.9 1.35 1.8 Miles

Figure 4: Household Income < 30K Density Data (Created by Michelle Nichols, Data Provided by San Diego Metropolitan Transit System (SDMTS)

Employment Data

As the regional center in San Diego County, the city of San Diego encompasses many characteristics that define the community. It includes urban neighborhoods, businesses, and communities surrounding the city center (Metropolitan Transportation Commission 2007). All these characteristics make downtown San Diego an ideal for Smart Growth development. High employment densities appear in central San Diego and in the far western section of the city. Bus routes and the LT system in the 2020 employment map (Figure 5), covers the western portion of the city, and the central portion is covered by numerous bus routes. The western section of the city, which includes a denser population of employees, is within walking distance from the central bus, SD-LRT, and the Coaster system (marked by the black circle).

Smart Growth benefits both employers and employees. The Environmental Protection Agency (EPA) has found that there is an increase in productivity when they have easy access and/or commute to work. Employees have the opportunity to live near where they work and have easy access to public transportation reducing an employee's commuting time benefit from experiencing less stress due to the short commute. In addition, the walkability factor in Smart Growth design can contribute to better employee health, thereby reducing healthcare costs.
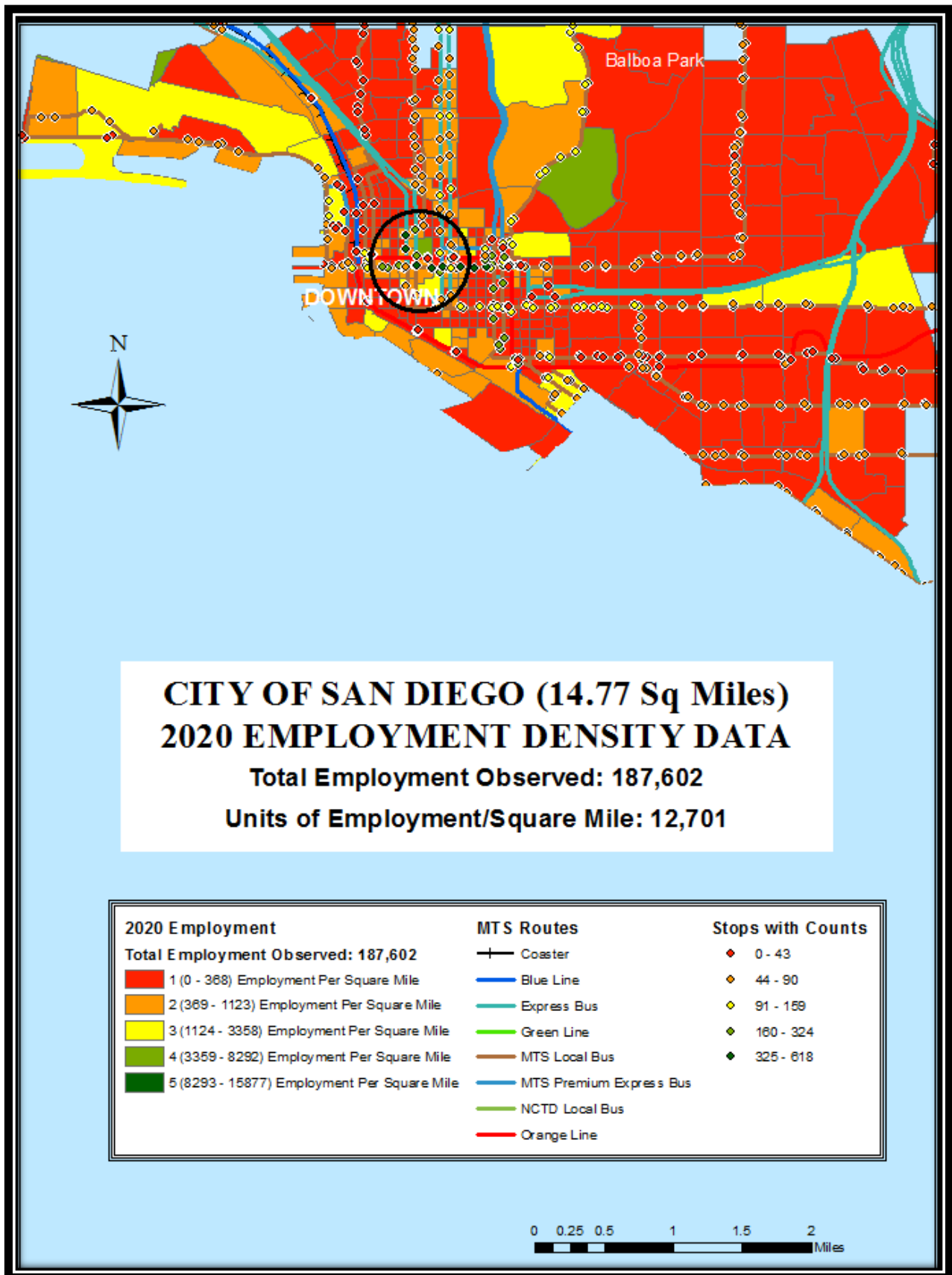
Figure 5: Employment Density Data (Created by Michelle Nichols; Data Provided by San Diego Metropolitan Transportation System [SDMTS])

Finally, businesses can attract more customers due to diversified commuting options and businesses will relocate to higher density Smart Growth/TOD areas (U.S. Environmental Protection Agency 2013).

Projected employment data were used to evaluate future employment densities. The employment map data in Table 4 were reclassified with less dense employment populations ranking lower than higher density employment populations.

Table 4: **Employment Re-Class Values** (Raster Cell Size .001/Area 14.77 Square Miles
Employment Observed: 187,602
Units of Employment Per Square Mile: 12,701

Values	Weighted Unit Values	Raster Counts
0-474 Employment Per Square Mile	1 (Red)	921,374
475-1694 Employment Per Square Mile	2 (Orange)	77,271
1695-4255 Employment Per Square Mile	3 (Yellow)	14,124
4256-15877 Employment Per Square Mile	4 (Light Green)	13,881
15878-44063 Employment Per Square Mile	5 (Green)	38,754

High Frequency Stop Service

In Smart Growth environments, the ideal bus and LT frequency stop counts should include stop frequencies every thirty minutes during non-peak hours and at least every fifteen minutes during peak hours. San Diego has several lines running throughout the day, and the downtown SD-LRT station includes low cost park-and-ride parking (Hogle Ireland, Inc. 2010).

Bus and SD-LRT stop frequencies were measured using the ArcGIS Kernel Density tool. Kernel Density layer inputs included an output cell size of = 50 and the search radius set at 1,320 or ¼ mile representing a walkable distance to the nearest stop. The individual bus stop frequencies were weighted by the actual stops (points) per stop site. Stop frequencies along the trolley corridor were quantified three (3) times the number of

original stops to represent the popularity of the SD-LRT system. This calculation was determined by SDMTS to represent the popularity of the light rail system when compared to the bus system. SDMTS found that when compared to the lower use of high frequency bus transit stops, commuters use light rail with less stops more frequently.

The darker green areas in Figure 6 signify a higher frequency of stops (points) along the routes and then tapers outward. Even with the weight added to the SD-LRT stops, bus stop frequencies displayed a higher density rating than SD-LRT. This could bring to light the importance of increasing the stop frequencies for SD-LRT. Due to the importance of the Orange Line section of the SD-LRT system, the three stops shown in the black circle on Figure 6 were expected to result in a higher Kernel Density ranking; however, this study revealed that those particular stops resulted in a less than average frequency level. The emphasis on the SD-LRT system results from the popularity and convenience of the system. SD-LRT routes extend throughout County of San Diego including routes south to the the San Ysidro Transit Center bordering Mexico, east into the City of El Cajon, and North of San Diego. A new system is spreading into the city of Chula Vista. Ridership to downtown San Diego is expected to increase (Tylin International 2012).

Rerouting and increasing the stop frequency in areas that are identified as present or future Smart Growth communities could encourage populations living near transit stops to take public transportation (Victoria Transportation Policy Institute 2014).
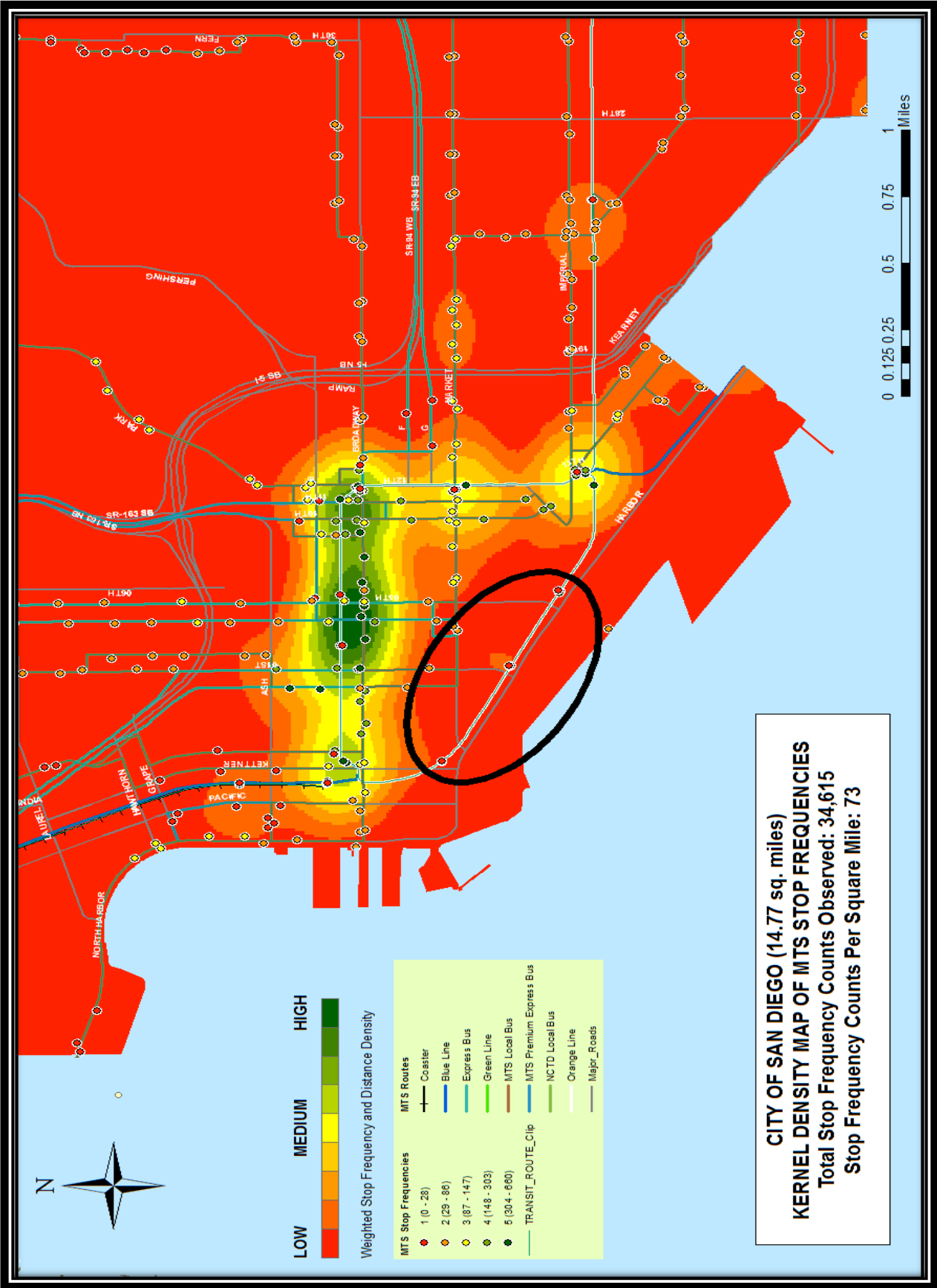
Figure 6: Stops and Counts Kernel Density. (Map Created by Michelle Nichols; Data Provided by the San Diego Metropolitan System [SDMTS])

Figure 7: SDMTS Stop Frequency Counts. (Map Created by Michelle Nichols; Data Provided by the San Diego Metropolitan System [SDMTS])

Figure 7 provides detailed stop frequency counts for the individual stops used in Figure 6. The highest frequency stop counts receive a weighted value of five (Green), while the lowest frequency stop counts received a low weighted value of one (Red) as listed in Table 5.

Table 5: Stop Frequency Re-Class Values (Raster Cell Size .001/Area: 14.77 Square Miles)
Total Stop Frequency Counts Observed 34,615
Stop Frequency Counts Per Square Mile: 773

Stop Frequency Values	Weighted Unit Values	Raster Counts
0-28	1 (Red)	111,223
29-86	2 (Orange)	47,612
87-147	3 (Yellow)	6216
148-303	4 (Light Green)	2805
304-660	5 (Green)	2370

Mixed Land Use

Mixed land use is described as one of the most crucial elements of Smart Growth identification and development (The Smart Growth Network 2006). The mixture of business, walkability, homes, jobs, and transportation options all support the Smart Growth development. California is not new to Smart Growth. Santa Barbara is recognized as one of the leaders in mixed land use management (Smart Growth America n.d.). Community planning and zoning in Santa Barbara endorsed building neighborhoods near or in the center of commercial centers. Being within the proximity of needed resources and entertainment creates active neighborhoods by encouraging residence to walk or bike. The more access local residents have to their everyday needs, the more pedestrians will fill the streets (The Smart Growth Network 2006).

Ridership is dependent on the characteristics of the neighborhood and its surrounding land use. Typically, land use was developed around automobile oriented transportation to accommodate large volumes of traffic. The Smart Growth developments reduce automobile oriented transportation needs by providing a variety of transportation options (Victoria Transportation Policy Institute 2014).

The types of buildings in potential areas identified as Smart Growth should include mid-rise to high-rise structures. This maximizes development on smaller land areas. Residential dwellings should be located within walking distance to commerce, recreation, and employment. Diversified businesses will attract local employment, which will in turn attracts a variety of new businesses to the area (Hogle Ireland, Inc. 2010).

Mixed land use also makes economic sense. Housing near commercial areas can raise the values of both commercial and private property. Local businesses benefit by being within close proximity of its consumers, and consumers benefit from spending less time traveling to meet their consumer needs (Hogle Ireland, Inc. 2010).

Table 6 reclassifies the type of land use into weighted zones shown in the Figure 8 map. Smart Growth utilizes compact high-rise building designs, and as a result, the rankings were based on the type of land use and its

space requirements. SDMTS requested the emphasis be placed on multi-residential units and high-rise office buildings. Weighted values were assigned to land use attributes according to population and community needs such as living and shopping. Family units were quantified by type of residence. Single-family detached units were ranked lower than single-family multi-units and multi-family residential units. Low-rise offices and hotels under five stories received a four ranking. Federal and state government offices received a five ranking due to their location and a high number of employees. The Federal buildings are also grouped together making access convenient using public transportation. Surface parking lots were ranked lower than high-rise parking structures due to the larger amount of cars that parking structures hold.
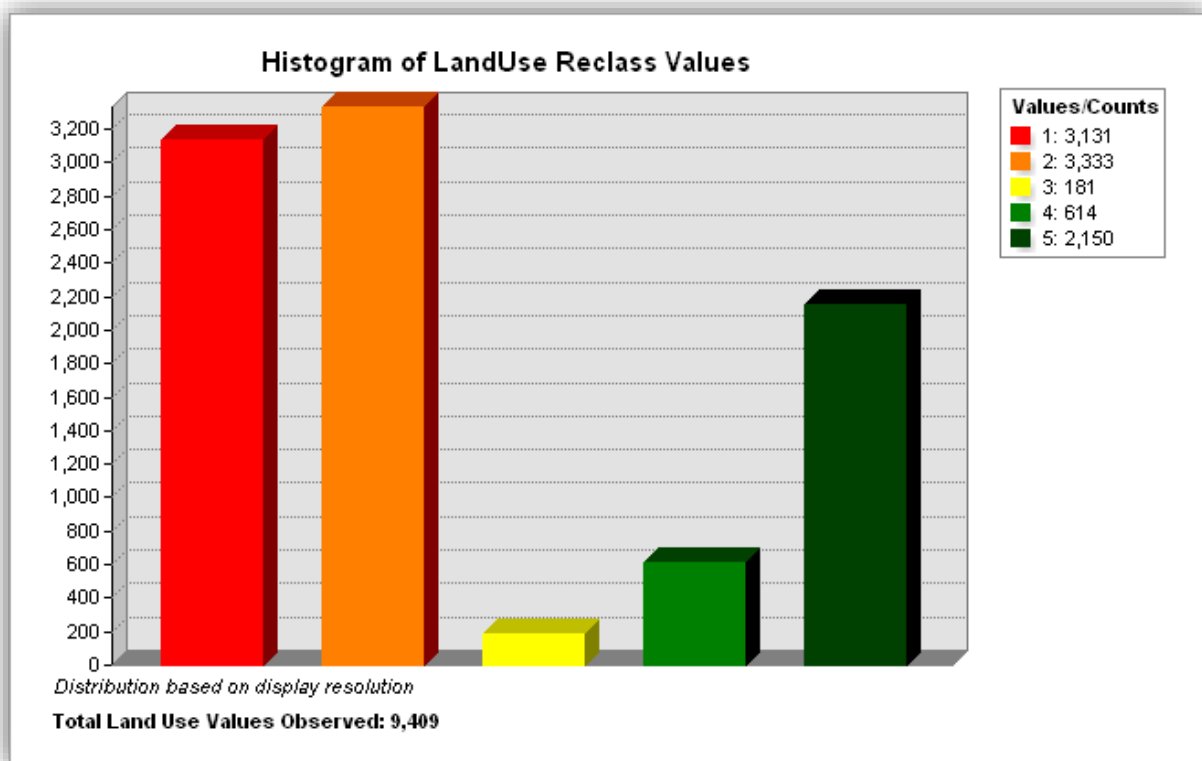
Figure 8: Histogram of Land Use Classifications

The land use shapefile provided the map data for the downtown San Diego area (Figure 8). Due to San Diego's already thriving business development, mixed residence in higher density structures were ranked at five, high-rise offices were ranked five, and public facilities such as low-rise office buildings were ranked at four. The structures ranked one through three covered larger areas of land and were not as significant in promoting Smart Growth as well as the higher ranked values.

The land use histogram (Figure 8) clearly shows a high number of one and two weighted values. At the other end of the graph, there are a moderate number of four and five weighted mixed land use features. The small number of higher weighted values allows for identifying specific areas where Smart Growth land use will contribute to the overall success of developing and sustaining the selected communities.

Table 6: Land Use Re-Class Values (Raster Cell Size .001/Area 14.77 Square Miles)

| Values/Total Counts	Weighted Values	Raster Cell Counts
Industrial Park/Light Industry - General/Public Storage/General Aviation Airport/Communications and Utilities/Religious Facility: Total 3,131	1 (Red)	12,118
Other Group Quarters Facility/Service Station/Other Retail Trade and Strip Commercial/Hospital - General/Other Recreation - Low: Total 3,333	2 (Orange)	2434
Single Family Detached/Mobile Home Park/Hotel/Motel (Low-Rise)/Resort/Freeway/Parking Lot - Surface/Wholesale Trade: Total 181	3 (Yellow)	206
Spaced Rural Residential/Single Family Residential Without Units/Office (Low-Rise)/Government Office/Civic Center/Post Office: Total 614	4 (Light Green)	41,180
Single Family Multiple-Units/Multi-Family Residential/Multi-Family Residential Without Units/Rail Station/Transit Center: Total 2,150	5 (Green)	40,602
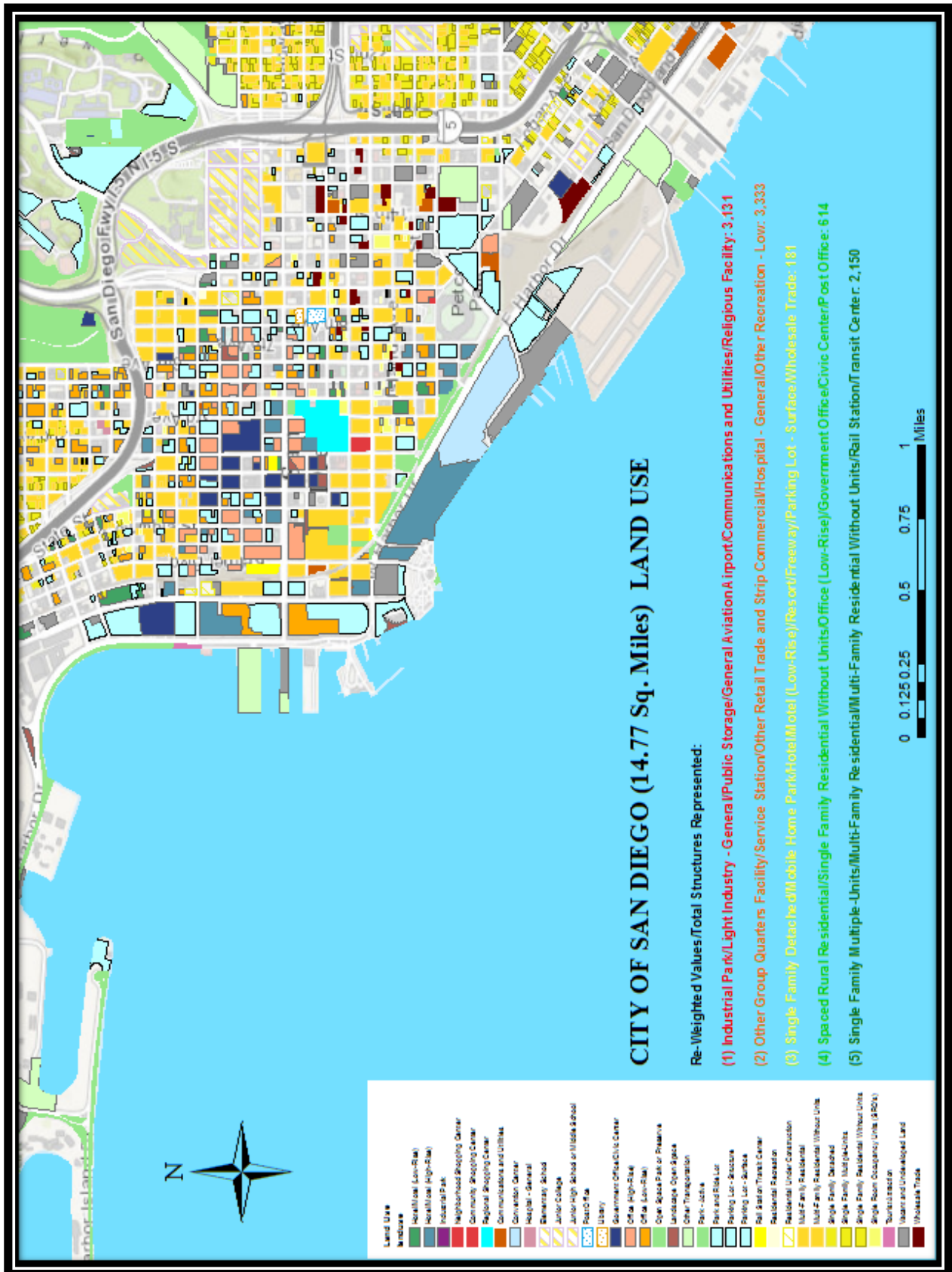
Figure 9: Land Use – Downtown San Diego (Created by Michelle Nichols; Data Provided by the San Diego Association of Governments [SanDAG])
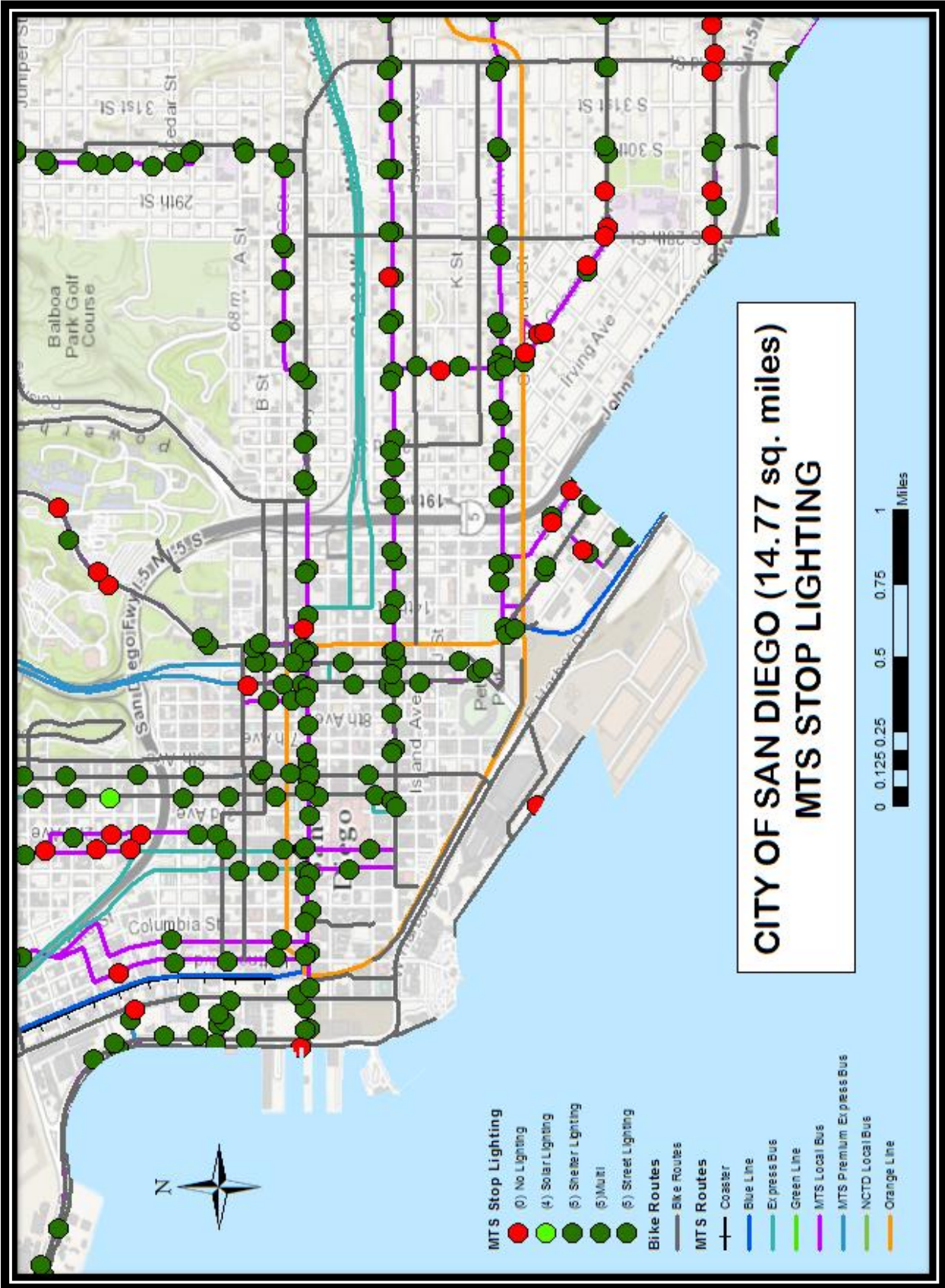
Figure 10: SDMTS Amenities - Lighting Map (Created by Michelle Nichols; Tiger/Line Shapefile Provided by the U.S. Census Bureau, and Amenities Table Provided by the San Diego Metropolitan Transit System (SDMTS)).

Lighting Amenities

The U.S. Department of Justice recommends providing well-lighted areas in an effort to reduce criminal activity. Safety is a great concern for anyone traveling after dark and well-lighted transit stops and stations make commuters feel more secure (MacKechnie n.d.).

Lighting data amenities were evaluated and weighted into three categories based on the type of lighting (Figure 10 and Table 7). The "No lighting/Can't Tell Other" categories were ranked as zero. Solar lighting was ranked below electric street lighting at four because lighting is provided, but was not ranked at five due to its reliability on weather conditions. Shelter, street, and multi-lighting were ranked at five because the system is hard wired to an electrical source.

The map (Figure 10) shows a majority of the transit stops provide sufficient lighting along the various commuter routes.

Table 7: Lighting Re-Class Values (Raster Cell Size .001/Area 14.77 Square Miles **)**

Values/Total Counts	New Values	Raster Counts
No Lighting/Can't Tell Other: Total 972	(0) (Red)	885
Solar Lighting: Total 7	(4) (Light Green)	6
Street Lighting/Shelter Lighting/Multi: Total 3354	(5) (Dark Green)	2664

Bicycle Routes

The bicycle route data serves two important purposes in this study. One, bicycle routes are one of the characteristics of a Smart Growth community. Two, for this study, bicycle routes were substituted for the lack of walkability data. People walk and bike for a variety of reasons. Recreation and exercise topped the 2012 National Survey of Pedestrian and Bicyclist

Attitudes and Behaviors (Pedestrian and Bicycle Information Center 2014).

Bicycling and walking contribute to reducing traffic congestion, and better

health. The survey in Table 8 reveals that bicycle transportation is good for

short to medium commutes, which can be extended when public

transportation provides facilities to lock up or carry bikes (Vermont Natural

Resources Council 2014).

Walking is another transportation option for those who are physically

capable. Most commuters walk one half mile or less. Providing transit stops

and stations within one half mile of a potential Smart Growth community

would be expected if the goal were to increase ridership (Pedestrian and

Bicycle Information Center 2014). It not only is close enough to walk, it is

also convenient for commuters if travel and wait time for public

transportation is a concern (Pedestrian and Bicycle Information Center

2014).

San Diego is a dangerous place for pedestrians. Out of every 100,000

pedestrians, 4.9 pedestrians will die each year, and between January and

March of 2013, 11 pedestrians were killed (Bledsoe and Grieco 2013). San

Diego was ranked by The National Highway Traffic Safety Administration

(NHTSA) as the nation's eighth most dangerous city for pedestrians (U.S.

Department of Transporation 2014). A safe walkable community is essential

in identifying potential Smart Growth communities; therefore, high

walkability scores are an important variable in the final calculations.
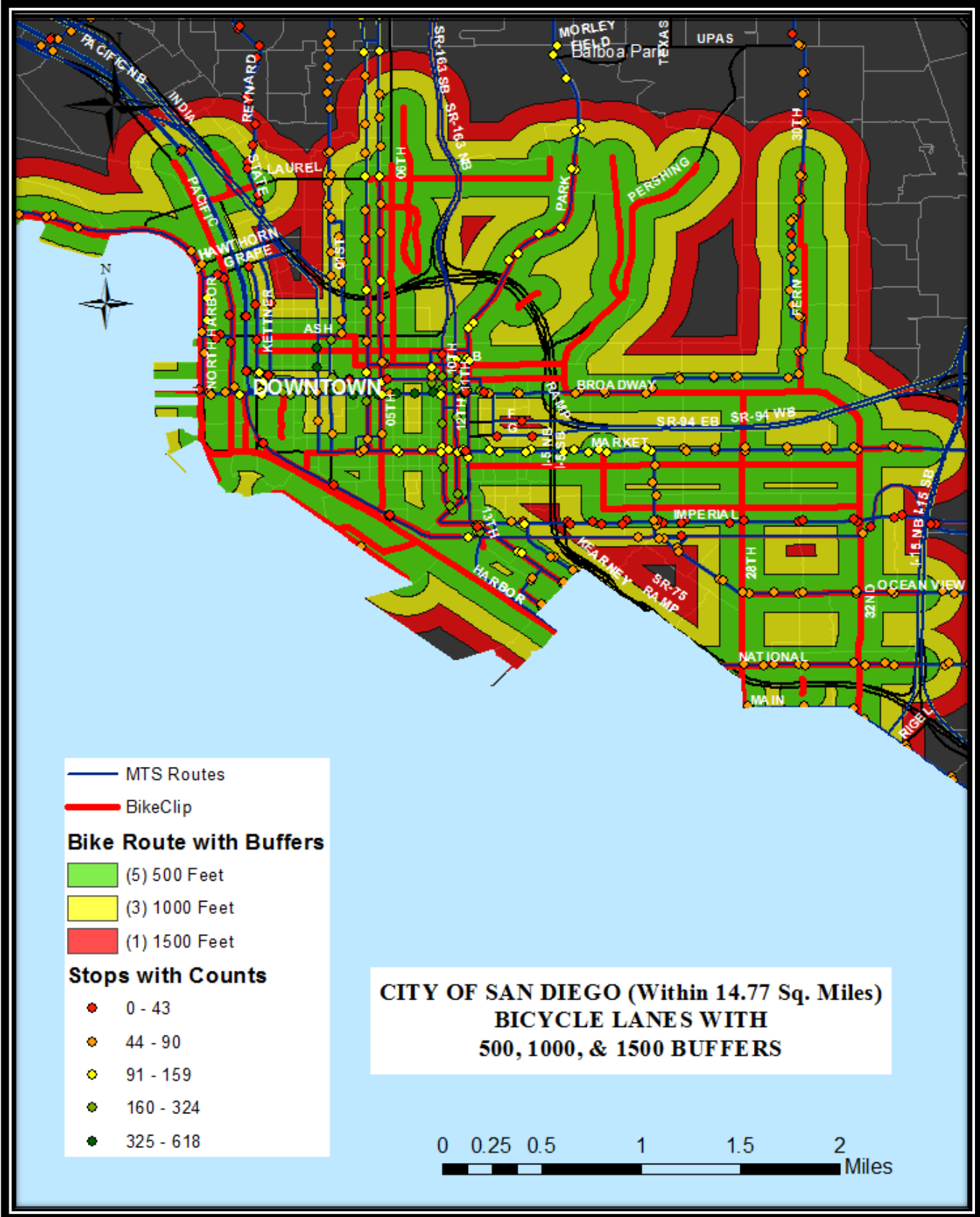
Figure 11: Bicycle Lane Buffers Data Map(Created by Michelle Nichols; Tiger/Line Shapefile Provided by the U.S. Census Bureau, and Bicycle Lane Data Provided by the San Diego Metropolitan Transit System (SDMTS))

A typical bike route in San Diego runs parallel in both directions between San Diego's streets and sidewalks. The map data were analyzed using walkability buffers at 500, 1000, and 1500 feet (Figure 11). Once the bike data were converted to a raster map, the fields were reclassified and weighted at 500 = 5, 1000 = 3, and 1500 = 1 (Table 9).

The reclassifications were based on the importance of the distance from the buffers to the sidewalk areas. The closer proximate of 500 feet was more desirable than the outer buffers. SDMTS maximized the longest amount of distance at 1500 feet. They determined that any distance outside of 1500 feet would not be considered a desirable walkability measurement to the nearest stops. Areas outside of the buffers received no ranking.

Table 8: Bicycling and Walking Data (Raster Cell Size .001/Area 14.77 Square Miles)

Description	Walking %	Bicycling %
Trip Length and Average Trip	26.9 .25 miles or Less	0-2 Miles/0-30 Min
	19.6 .26-0.5 miles	2-4 Miles 31-36 Min
Reasons for Participating	39 Exercise	33 Recreation
	17 Personal Errands	28 Exercise/Health
	15 Recreation	11 Commuting
Pacific Area	10.6 (2nd Highest)	1.1 (Highest)
Facilities Used	45.1 Sidewalks	48.1 Paved Roads
	24.8 Paved Roads	31.6 Sidewalks
	8.4 Shoulders	13.1 Bike Routes

Source: Data from the 2012 National Survey of pedestrian and Bicyclist Attitudes and Behaviors (Pedestrian and Bicycle Information Center 2014)

Table 9: Bike Route/Walkability Re Class Values (Raster Cell Size .001/Area 14.77 Square Miles)

Values in Feet	New Values
1500	1 (Red)
1000	3 (Yellow)
500	5 (Green)

Additional Stop Amenities

For supplementary analysis, three additional amenities were included for evaluating stops that provided routing maps, benches, and shelters (Figure 12). The weighted values for the additional amenities were added to the final calculation and a separate map was created for comparison to the map that included only the lighting amenity (Figures 16 and 17).

Although these amenities are not necessarily required, providing additional amenities will make the commuting experience more comfortable and convenient. Attracting and keeping long-term commuters can depend a lot on the aesthetics and the safety of the commuting environment (Bekker 2014). Moreover, commuters feel less inconvenienced when amenities are provided. Sitting rather than standing gives passengers the impression of experiencing a shorter waiting time. A low-lit environment could make a person feel vulnerable, and as a result, due to the person's constant awareness, the waiting time might feel longer. Moreover, unsafe walking conditions and poor sanitation can also make commuters feel uncomfortable. (Bekker 2014). These circumstances make it difficult for a person who experiences the feeling of being vulnerable to return to the same environment. One the other hand, providing a safe, clean, and convenient transit experience gives commuters the impression that they were not waiting long (Bekker 2014).
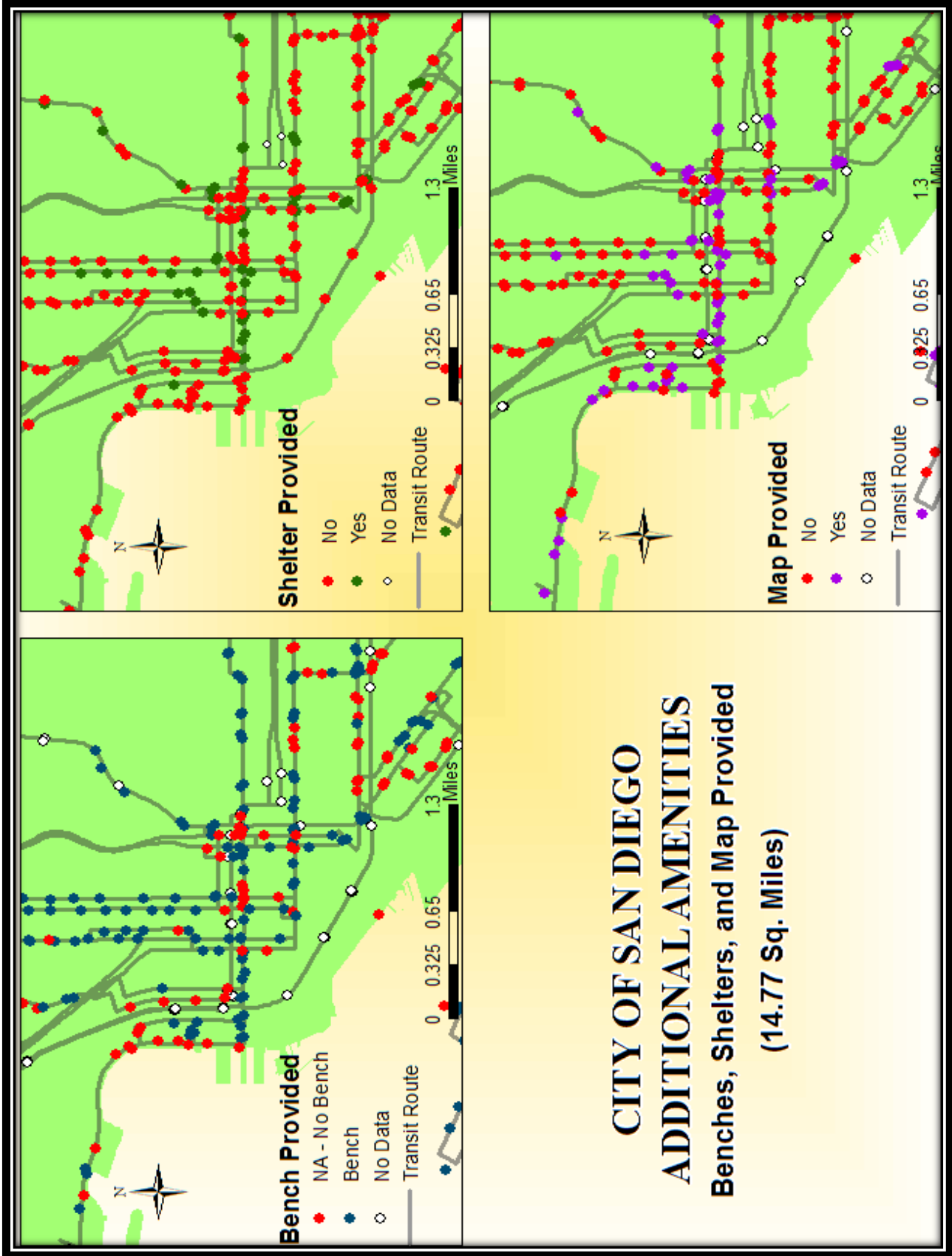
Figure 12: Additional Transit Amenities (Created by Michelle Nichols, Data Provided by San Diego Metropolitan Transit System)

Spatial Analysis

The final step in analyzing all the data required spatial analysis of the raster layers consolidated into one raster map with total cell values.

The resulting demographic data in Figure 13 was right skewed because of the larger mean values compared to the median values seen in Table 10. The weighted calculations represented in the all four data sets are larger within the lower density values. Consequently, larger cell values would be less frequent in the final calculated raster cell data, and the lower cell values will be more frequent. With the larger densities occurring less frequently, spatial analysis exposed the higher weighted cell values within the maps. The resulting higher weighted cell data (symbolized from red [lowest] to green [Highest]) will be evaluated to identify areas as potential Smart Growth/TOD communities.

The Figure 16 mapped cell values, supported by the values shown in the histogram of spatial analysis (Figure 14), demonstrates where the majority of calculated cells in special analysis map without all amenities (Figure 16) are distributed. The higher valued cells occurred less frequently, while the majority of the remaining cell values occurred centrally within the histograms. According to the data in the Table 14 histogram, the higher cells values should be easier to identify since they occur less frequently.

Before calculating, all the maps were converted into raster formats and values were reclassified into one (lowest) through five (highest)

rankings. The raster maps were then calculated using Map Algebra and the final map cell statistics were generated using the ArcGIS tool.
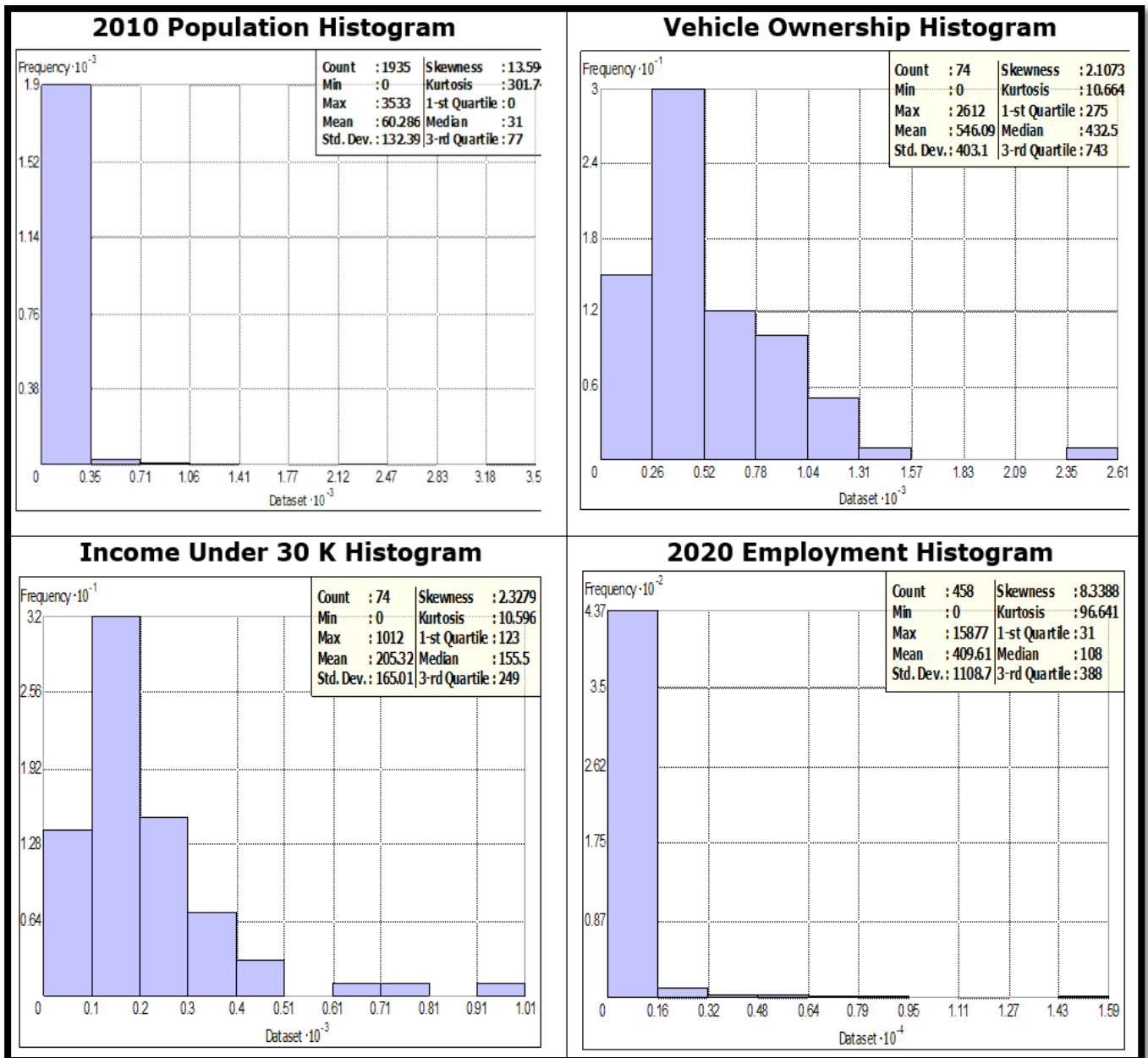

Figure 13: Demographic Histograms. Source: Data from San Diego Metropolitan Transit System (SDMTS) and the National Historical Geographic Information System (NHGIS)

Table 10: Map Statistics Raster Calculation Tables (Raster Cell Size .001/Area 14.77 Square Miles)							
Data	**Sum**	**Min**	**Max**	**Count**	**Median**	**Mean**	**Std. Dev(s)**
Population	57,454	0	3533	1935	31	60.29	132.39
Vehicles	40411	0	2612	74	433	546	403.1
Employment 2020	111,112	0	15877	458	108	410	1108
Income < 30 k	245565	0	1589	1794	110	137	115

Figure 16 was calculated by weighted cell values assigned to Stop

Frequencies, Lighting, 2010 Population, Employment, Income Under 30K,

Land Use, and Vehicle Ownership. The resulting high/low cell counts in

Figure 14 histogram representing the Figure 16 final map calculations are

between four and twenty-nine. Cell counts with the highest and lowest

weighted values occurred less often, while the central values occurred more

often. Areas of Smart Growth potential were identified through this process

identified within the black circles in Figure 16. Higher concentrations were

clustered in the center of the city and two other identifiable clustered areas

were evident as the data spread outward.

Figure 17 combines all cell values used in Figure 16 (Stop Frequencies,

Lighting, 2010 Population, Employment, Income Under 30 K, Land Use,

Vehicle Ownership data) and additional amenities were added to the

calculation including benches, maps, and shelters to determine the final cell

statistics.

Once the three additional amenities were added, individual cell counts

increased between thirteen to thirty-nine counts per cell. The Histogram in

Figure 15 shows the cell counts for the raster map with all amenities

calculated (Figure 17). Compared to the Figure 15 Histogram, Figure 16's

higher cell calculation occurred at a higher frequency rendering the cells less

cluttered in the Figure 17 map when compared to the Figure 16 map. The

The histogram in Figure 14 displays a slight skew to the left for the map in

Figure 16 revealing clusters of areas with Smart Growth potential (identified

within the black circles). The additional amenities data in the Figure 17 map skewed the cell count results slightly to the right (Figure 15). As a result, outcome of the cell values circled in Figure 17 reveal Smart Growth areas randomly spread throughout the downtown area of San Diego. Most were located on transit stops along the light rail infrastructure.
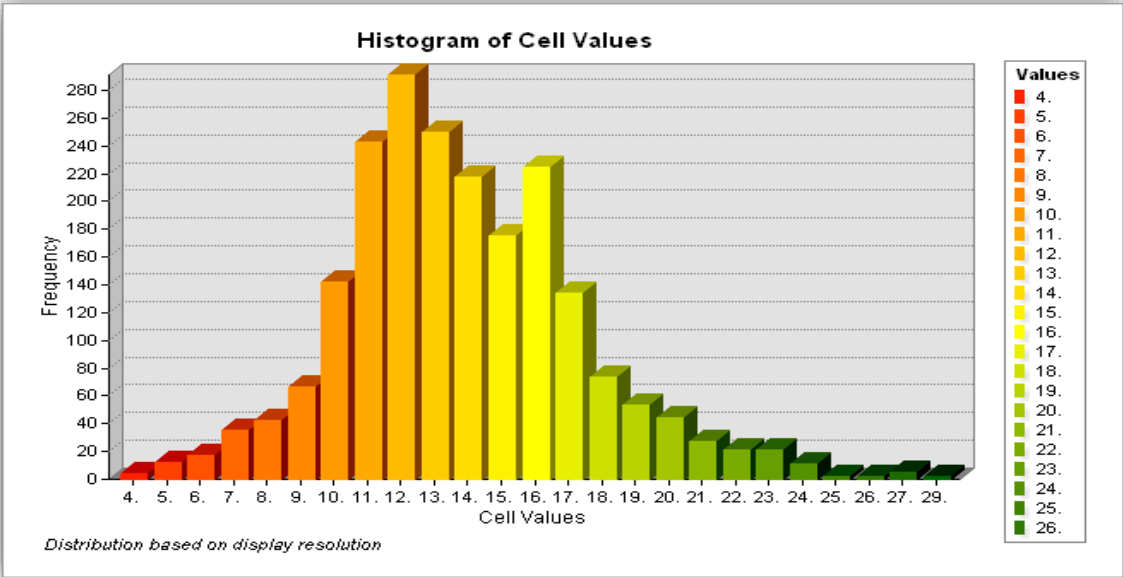

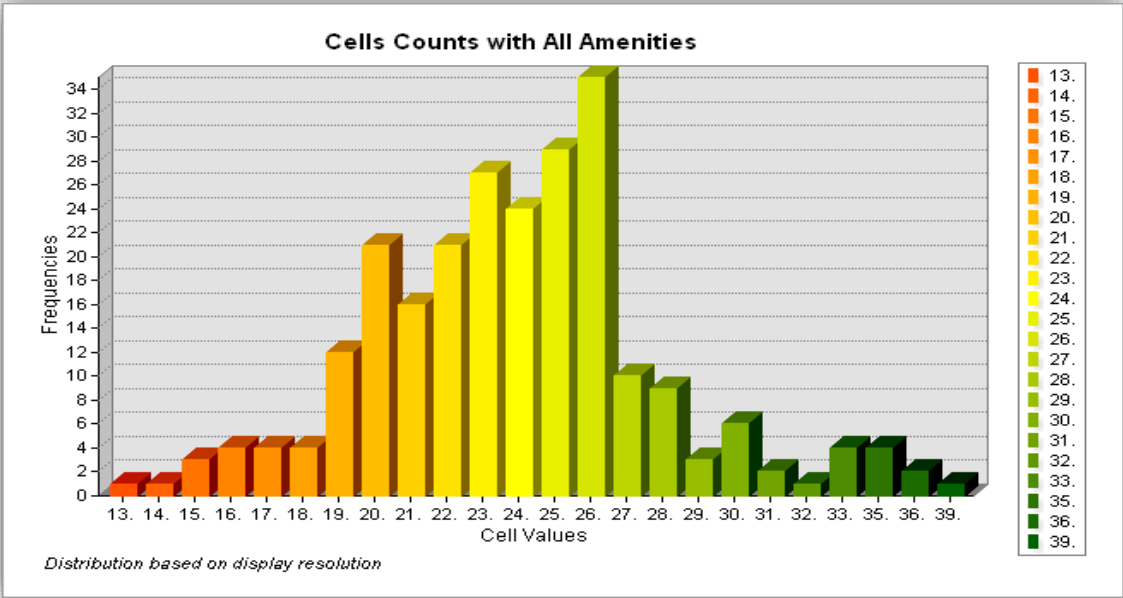**Figure 14: Histogram of Spatial Analysis Results**

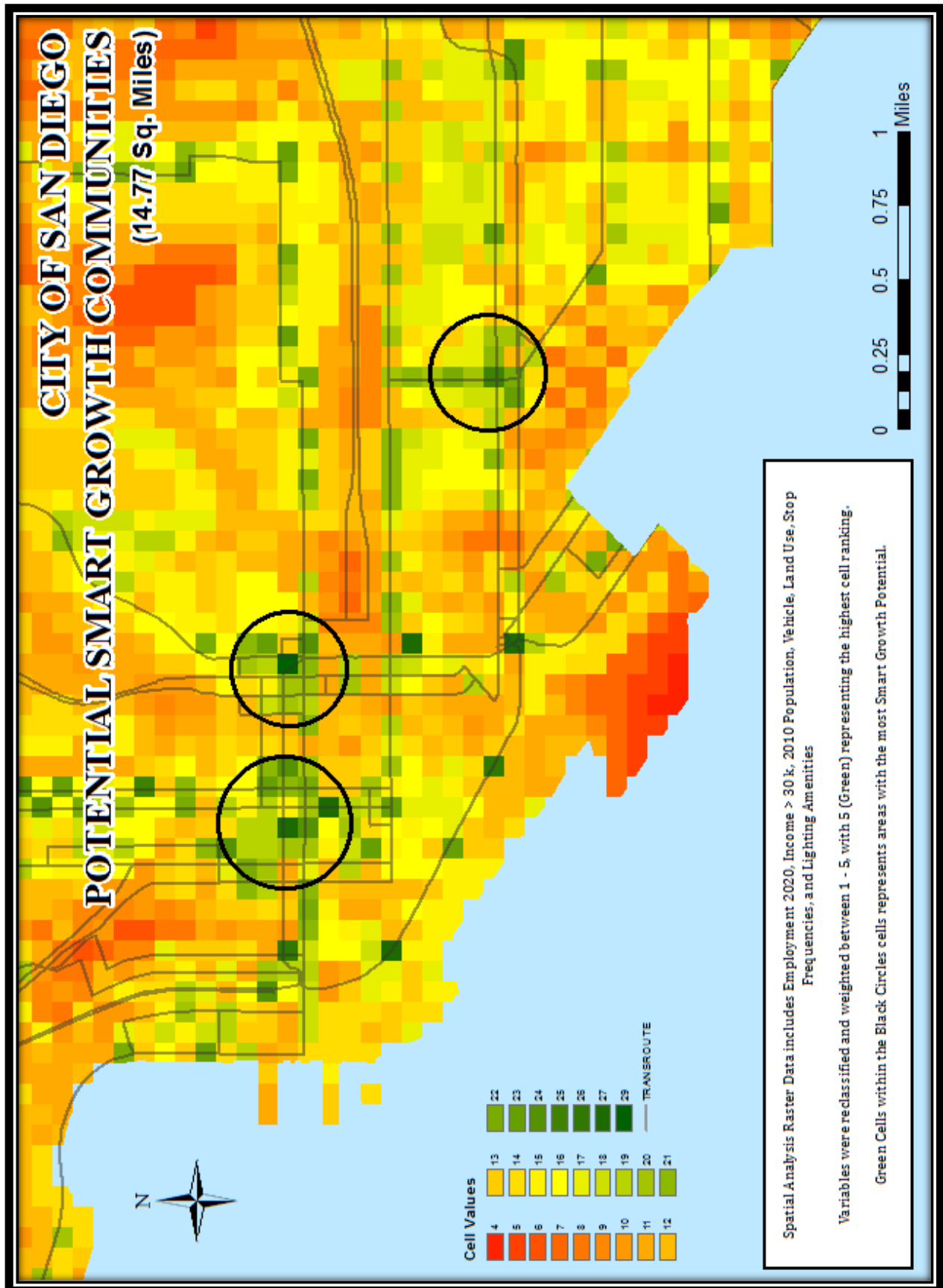**Figure 15: Cell Counts with All Amenities**

Figure 16: Spatial Analysis of Selected Map Layers (Created by Michelle Nichols Data Provided by San Diego Metropolitan Transit System (SDMTS), U.S. Census Bureau, and the National Historical Geographic Information System (NHGIS))
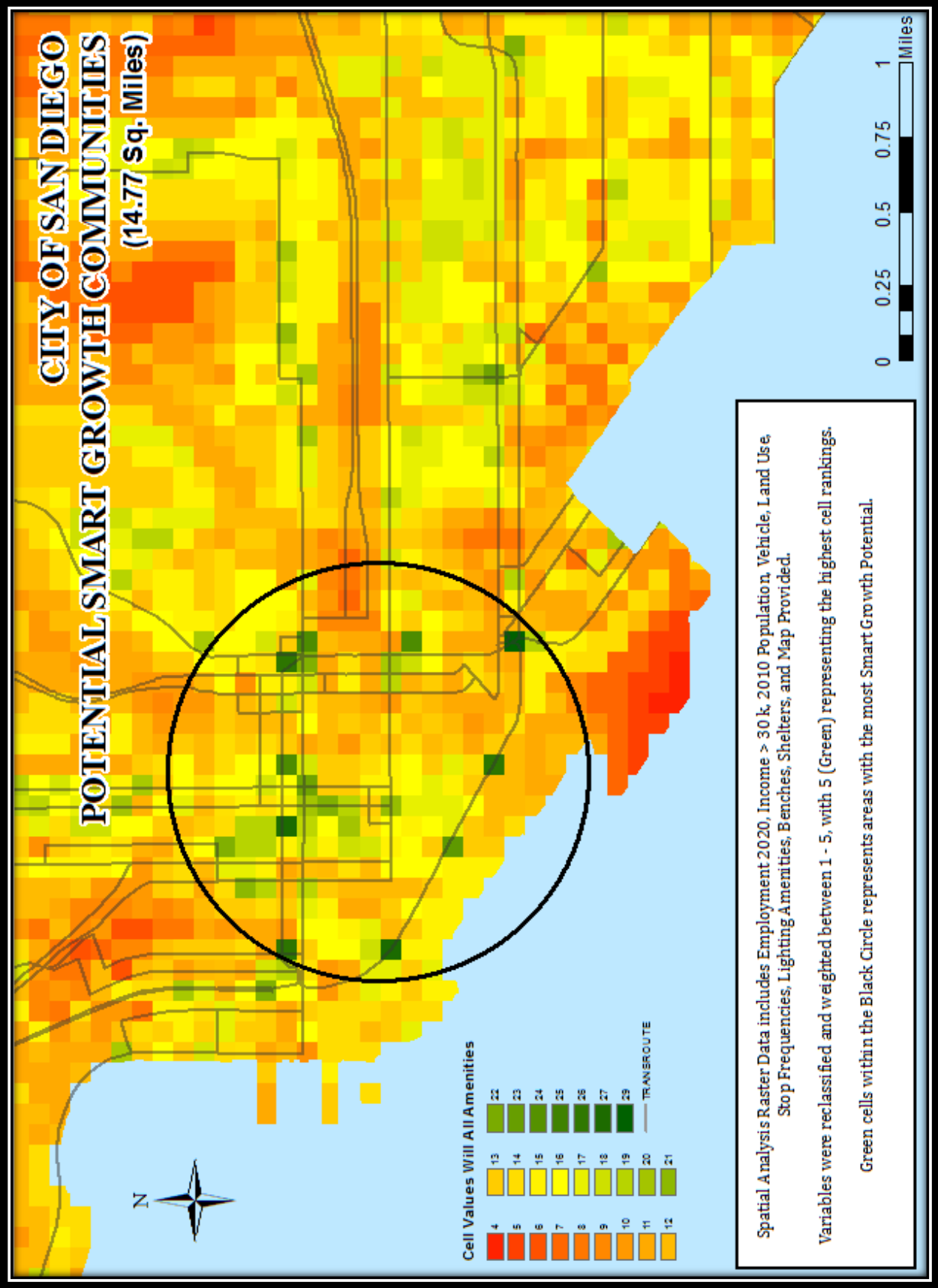
Figure 17: Spatial Analysis of All Map Layers Created by Michelle Nichols Data Provided by San Diego Metropolitan Transit System (SDMTS), U.S. Census Bureau, and the National Historical Geographic Information System (NHGIS)
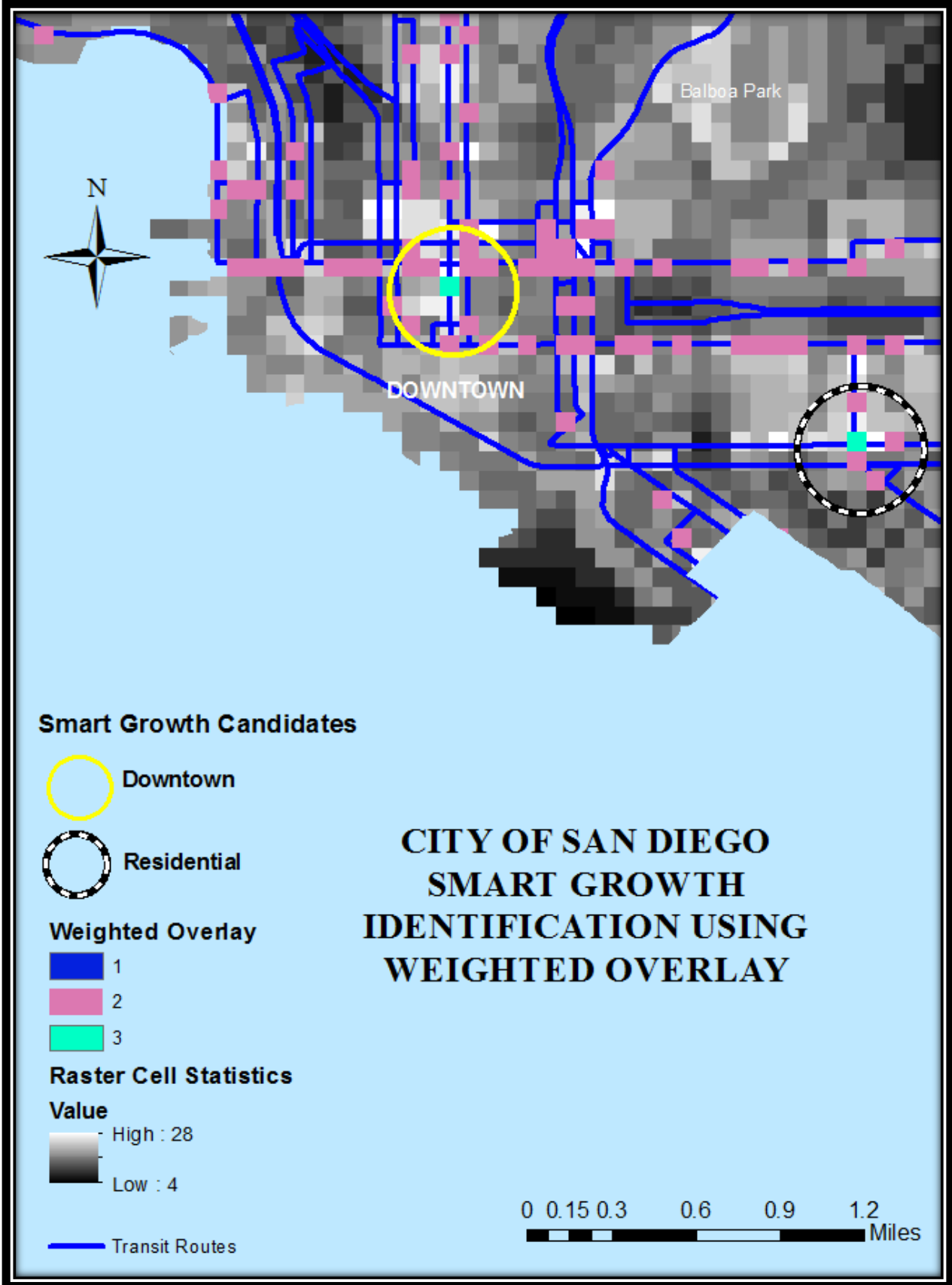
Figure 18: Weighted Overlay Calculations Created by Michelle Nichols Data Provided by San Diego Metropolitan Transit System (SDMTS), U.S. Census Bureau, and the National Historical Geographic Information System (NHGIS)

Weighted overlay calculations were used as the final map created for analysis (Figure 18). The weighted overlay revealed two strong Smart Growth areas in the downtown San Diego as having a high value of Smart Growth potential (marked with yellow and black/white circles in Figure 18). The area circled in yellow identifies the downtown area with the highest cell value and the area within the black/white circle identifies a residential area with the highest cell value. Using both the statistical outcomes, the marked cells were identified as having the overall highest potential through the weighted values assigned to each variable.

Additional Data Requested by SDMTS

SDMTS requested additional data for future use. The employment and population density data in Figure 19 will be used in addition to the weighted raster maps as a reference to the density of the employment and population groups served by Smart Growth choices.

Population and Employment Point Analysis

A pattern of employment in the city's center with population increasing further away from the city center is evident in the point density map in Figure 19. Employees represent most of the population density in the city center. Residential population densities are more frequent and scattered as the data spreads away from the city. The western edge of the city where tourism is the primary commerce is more employee-dependent. Between the western part of the city and city center, high-rise residential housing is

City of San Diego
2010 Employment and 2010 Population Density Map

Observed Area: 14.77 Sq. Miles
Population Density Per Sq. Mile: 3,890
Employment Density Per Sq. Mile: 7,523

Employment & Population Data

1 Dot = 25

• Population (Total 57,454)
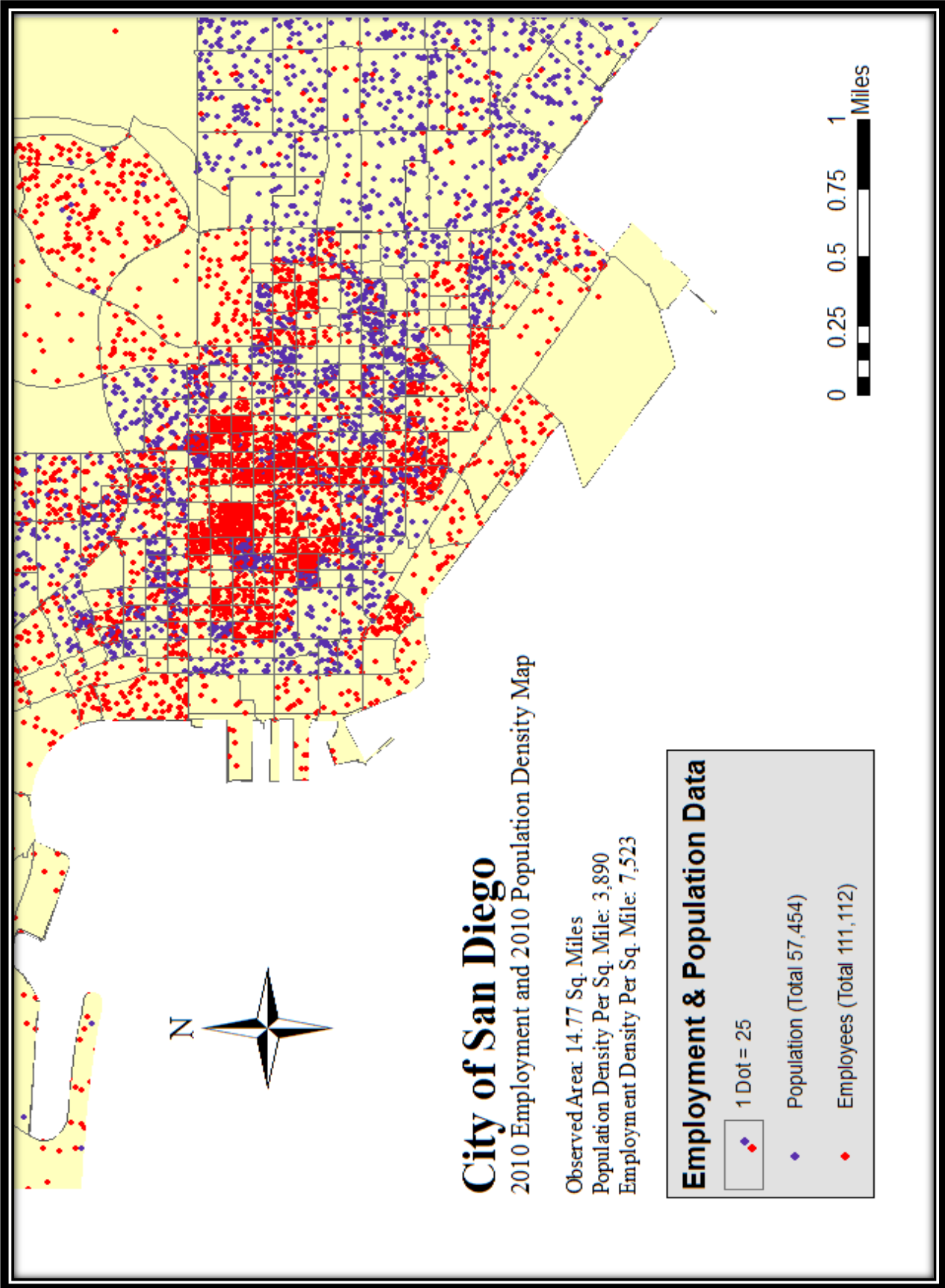
• Employees (Total 111,112)

Figure 19: Employment and Population Point Density Data:

Scheduling stop frequency around residential and employee characteristics may increase ridership if the frequency of stops coincide with what the type of population being serviced. More stop frequencies may be required during times where employee commuting are at its highest, while steady frequent stops near higher populated areas are needed to serve the public.

Database for Future Use

As geographic data were processed and compiled, a geodatabase was created with all the data needed for analysis of this study. Present and future demographic .csv and .xlxs data tables were also included that contained additional attributes and amenities for further study. All the map types, including the graduated and point analysis maps, the raster conversion maps, and the reclassified data were all stored for quick reference.

DISCUSSION

Identifying areas with Smart Growth potential on an already existing public transportation infrastructure requires the examination of several characteristics that will enable transportation decisions that support further Smart Growth developments. It is not cost effective in the current economy to build a new transportation infrastructure. SDMTS' goal is to use this study to review the current transit system and redesign the routing system to support communities that have some or all of the existing Smart Growth characteristics.

The spatial analysis in both Figure 16 and 17 maps produced several areas that are Smart Growth compliant. After the maps were analyzed for potential Smart Growth development, it was decided that more emphasis would being placed on the calculated data without the additional amenities in Figure 16 and comparing the data to the weighted overlay data for verification. Using the data that included all the calculations in Figure 17 would limit the identification of potential Smart Growth developments to fewer heavily weighted cells. Eliminating the additional amenities pushed the focus onto population, employment, vehicles and amenities such as stop frequencies, walkability and lighting. This map provides a larger range of areas to consider for Smart Growth development.

If SDMTS bases Smart Growth decisions on the analysis using the final weighted overlay calculations in Figure 18, the two areas identified are strong candidates for Smart Growth development. For reference, the yellow circle marks the downtown areas and the black and white circle marks the residential candidate in the southern portion of the city. Both the candidates selected fall within income levels that represent the highest portion of those making less than $30,000 per year. The population varies between medium to low-density populated areas. The downtown candidate has a larger number of employees compared to the candidate located south where residential population is higher. Vehicle ownership values for both candidates are ideal at the low ownership range. Land use for the downtown area is primarily commercial. The residential candidate encompasses residential housing and

commercial use. Walkability for the downtown candidate is within the five hundred and one thousand foot range, and the residential candidate falls within the fifteen hundred foot walkability range.

GIS is a technology that makes it possible for communities to reevaluate current conditions and improve the environment based on these assessments. The results of this study are a valuable part of the outcome of SDMTS' ultimate objective, which is to improve ridership and support the surrounding community by reducing the negative effects of population. The process of converting weighted values into visual map data gives the engineers at SDMTS the visual tools needed to make the most informed choices.

AREAS FOR FURTHER RESEARCH

Data for walkability are needed to render the analysis more precise in terms of the walkable access to and from transit stops. Walkability data for this research are currently being collected and should be available soon.

Including the current zoning policy for the Smart Growth areas identified would be helpful for revisiting and planning new transportation strategies. If planning and development in the area will bring in new residents, commerce, or other Smart Growth characteristics, decisions can be made to support future Smart Growth through public transportation. On the other hand, if zoning projects will reduce the potential for Smart Growth development that information would be valuable in reevaluating the area's transportation needs and possibly shifting resources to better serve potential Smart Growth communities.

REFERENCES

Abukhater, Ahmed, and Doug Walker. 2010. *Making Smart Growth Smarter with GeoDesign - Directions Magazine.* July 19. Accessed June 8, 2014. http://www.directionsmag.com/articles/making-smart-growth-smarter-with-geodesign/122336.

Arrington, GB. n.d. *TOD in the United States: The Experience with Light Rail.* Portland: PB PlaceMaking.

Bekker, Jessie. 2014. "Twin Cities Daily Planet." *The Minnesota Daily.* September 17. Accessed October 18, 2014. http://www.tcdailyplanet.net/news/2014/09/17/bus-stop-amenities-shorten-wait.

Bledsoe, Greg, and Sarah Grieco. 2013. "San Diego Dangerous for Pedestrians: Report." *NBC San Diego.* August 9. Accessed October 31, 2104. http://www.nbcsandiego.com/news/local/San-Diego-Dangerous-for-Pedestrians-Report-218448261.html.

Boarnet, Marlon G. 1998. "Business Losses, Transportation Damage, and the Northridge Earthquake." *Journal of Transportation and Statistics* 49-63.

Boroski, John, Topaz Faulkner, and GB Arrington. 2002. *Parking and TOD: Challenges and Opportunities.* Business Transportation and Housing Agency.

Brady, Mike, and Micah Brady. 2013. *Santa Ynez Land.* Accessed October 1, 2013. http://santaynezland.com/local_info.php.

Cervero, Robert. 2008. *Effects of TOD on Housing, Parking, and Travel.* TCRP Report 128, Washington, D.C.: Transportation Research Board.

Envision Utah. n.d. *Transportation & Communities.* Accessed August 13, 2014. http://envisionutah.org/issues/transportation-communities.

Ewing, Reid. n.d. "Pedestrian and Transit -Friendly Design: A Primer for Smart Growth." *Smart Growth Network.* Accessed August 7, 2014. www.smartgrowth.org.

Ewing, Reid, Pendall Rolf, and Don Chen. 2002. *Measuring Sprawl and Its Impact - Volume 1.* Washington D.C. : Smart Growth America.

Ferris, Hal. 2011. *Developing the Next Frontier: Capatalizing on Bus Rapid Transit to Build Commuity.* Urban Land Use Study, Seattle: Urban Land Institute.

Goetz, Andrew. 2013. "Suburban Sprawl or Urban Centres: Tensions and Contradictions of Smart Growth Approaches in Denver, Colorado." *Urban Studies, 50, Issue 11* 2178-2195.

Havens, Chris. 2010. *Central Corridor Isn't Just about Moving People.* March 14. Accessed June 9, 2014. http://www.startribune.com/local/minneapolis/87598407.html.

Hoffman, Joel. 2014. "VA Clinic Access in Question." *UT San Diego.* September 12. Accessed September 12, 2014. http://www.utsandiego.com.

Hogle Ireland, Inc. 2010. *Western Riverside Smart Growth Opportunity Area Map.* Report, Irvine: Hogle-Ireland, Inc.

Leinberger, Christopher B., and Patrick Lynch. 2014. *Foot Traffic Ahead: Ranking Walkable Urbanism in America's Largest Metros.* Real Estate and Urban Analysis, Washington, DC: LOCUS.

Litman, Todd. 2014. "New Research On Smart Growth Benefits ." *Planetizen.* April 21. Accessed October 15, 2014. http://www.planetizen.com/node/68408.

MacKechnie, Christopher. n.d. "Lighting at Bus Stops." *About Money.* Accessed October 1, 2014. http://publictransport.about.com/od/Transit_Infrastructure/a/Lighting-At-Bus-Stops.htm.

Metropolitan Transportation Commission. 2007. *Reforming Parking Policies to Support Smart Growth.* Study, Oakland : MTC/ABAG.

Moeckel, Rolf, and Rick Donnelly. 2014. "Gradual Rasterization: Defining the Spatial Resolution in Transport Modeling." *Transportation Research Board in Washington, D.C.* Alburquerque: Parsons Brinckerhoff. http://smartgrowth.umd.edu/gradualrasterizationredefiningthespatialresolution.html.

National Historical Geographic Information System. n.d. "Minnesota Population Center. National Historical Geographic Information System: Version 2.0. ." *National Historical Geographic Information System.* Accessed October 10, 2014. www.nhgis.org/documentation/tabular-data.

Parker, Terry, Mike McKeever, GB Arrington, and Janet Smith-Heimer. 2002. *Statewide Transit-Oriented Development Study: Factors for Succes in California.* CalTrans, Business, Transportation and Housing Agency.

Pedestrian and Bicycle Information Center. 2014. "Who's Walking and Bicycling." *Pedestrian and Bicycle Information Center.* Accessed

November 3, 2014.
http://www.pedbikeinfo.org/data/factsheet_general.cfm.

Popescu, Roxana. 2013. "U-T San Diego." *When a Casino Gets Built, Does the Neighborhood...* June 9. Accessed October 15, 2013. www.utsandiego.com/news/2013/Jun/09/tp-when-a-casino-gets-built-does-the-neighborhood/2/?#article-copy.

Rapacon, Stacy. 2014. "America's 10 most expensive cities to live in, 2014 ." *Kiplinger.* Accessed October 22, 2014. America's 10 most expensive cities to live in, 2014 .

Ratner, Keith A., and Andrew R. Goetz. 2013. "Reshaping of Land Use and Urgan Form in Denver through Tranist-Oreinted Development." *Cities 30* 31-46.

Sierra Club. 2000. *New Research on Population, Suburban Sprawl and Smart Growth.* Accessed October 1, 2014. http://vault.sierraclub.org/sprawl/whitepaper.asp.

Smart Growth America. n.d. *Economic Benefits of Smart Growth.* Accessed June 8, 2014. http://www.smartgrowthamerica.org/locus/issues/economic-benefits-of-smart-growth.

The Smart Growth Network. 2006. *Why Smart Growth.* Accessed October 30, 2014. http://www.smartgrowth.org.

Tucker, Tashieka, Jeremy Wilhelm, Chad Wingate, Joe Winters, and Luke Wilkinson. 2008. "Smart Growth and Transit Oriented Development." *American Planning Association: Georga Chapter.* April 21. Accessed August 8, 2014. https://georgiaplanning.org/.

Tumli, Jeffery, and Adam Millard-Ball. 2013. "How to Make Transporation-Oriented Development Work." *American Planning Association* 14-19.

Tylin International. 2012. *Chula Vista Light Rail Corridor Improvements Project Study Report.* San Diego: City of Chula Vista.

U.S. Department of Transporation. 2014. "Traffic Safety Facts 2012 Data." *National Highway Traffic Safety Administration.* April. Accessed December 28, 2014. http://www-nrd.nhtsa.dot.gov/Pubs/811888.pdf.

U.S. Environmental Protection Agency. 2013. "Smart Growth." *EPA.GOV.* October 30. Accessed September 13, 2014. http://www.epa.gov/smartgrowth/topics/rural.htm.

—. 2013. "Smart Growth and Economic Success: The Business Case." *Smart Growth.* November. Accessed October 1, 2014. www.epa.gov/smartgrowth.

United States Census Bureau. 2014. Accessed December 10, 2014.
    https://www.census.gov.

Vermont Natural Resources Council. 2014. *Land Use Planning/Smart Growth.*
    Accessed October 1, 2014. http://vnrc.org.

Victoria Transportation Policy Institute. 2014. "TDM Encyclopedia." *Smart
    Growth: More Efficient Land Use Management .* June 4. Accessed
    November 5, 2014. http://www.vtpi.org/tdm/tdm38.htm.