Where Does BART Belong?
Optimizing the Placement of Additions to the Bay Area's Transit System

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EVST 290a
Fall 2012

***Abstract**:* The Bay Area Rapid Transit system (BART) is a subway and train system in Northern California that connects the East Bay to San Francisco and select parts of the peninsula. While it is a reliable and quick network, its weakness lies in its minimal extent. In this project, I synthesize modern-day information about population concentration, existing public transportation routes, topography, income distribution and job density to deduce the optimal placement of a new branch of BART.

Figure 1: Jake Coolidge, *The BART System That Never Was,* 2011. Available from: Jake Coolidge Cartography, http://www.jakecoolidgecartography.com/2011/10/27/the-bart-system-that-never-was/ (accessed December 10, 2012).

***Introduction**:* When BART was originally conceived in the 1950s, planners visualized a transit system that would encircle the San Francisco Bay, connecting the far reaches of Napa County with the most southern reaches of Santa Clara County. For various reasons – costs and certain counties' objections to hosting transit stations – only a fraction of the system was ultimately implemented. Today, BART connects a wide swath of the East Bay with just a sliver of Southeastern San Francisco and runs as far as Millbrae on the peninsula. While the system itself is relatively reliable, fast and cheap, it is weakened by its minimal extent in San Francisco and its bulky interface with other transit systems.

While BART's situation has attracted some redesign enthusiasm, most of that has been directed towards the new BART map that was introduced in 2010, and the 2011 BMW refresh of the physical trains. Indeed, little attention has been afforded to the idea of actually revising the reach of the BART lines themselves. For historical context, it's interesting to note the planning commission's original plans. Jake Coolidge, a Bay Area-based cartography and transit specialist, constructed a map of what the BART system could have looked like, had the full extent of the plans ever been realized (Fig. 1). This map of the transit system, dreamed but never constructed, is compared to a map of the current BART system to highlight some of the systems' shortcomings (Fig. 2).

Figure 2: BART System Map, 2010. Available from: http://www.bart.gov/stations/index.aspx (accessed December 10, 2012).

My work will differ significantly from Jake Coolidge's work. My focus will be deciding intelligently and algorithmically upon locations for a *new* BART route, based on the area's current conditions, rather than diagraming what had been planned in the 1950s. Additionally, my study primarily focuses on San Francisco, whereas other work has been scoped to the entire Bay Area. I find both personal and academic motivations for this study. As a Bay Area native

who is fascinated by public transportation, I have a very personal relationship with BART and am well acquainted with its shortcomings. On a higher level, I consider this project a useful opportunity to acquaint myself with ArcGIS, because improving the efficacy and reach of public transit systems is a good way to alleviate environmental pollution and ease the financial burden on the city's poor.

***Objective**:* The aim of this project is to use data on population and job density, socioeconomic factors, city topography, and existing public transportation systems to optimize the placement of a new branch of the BART system.

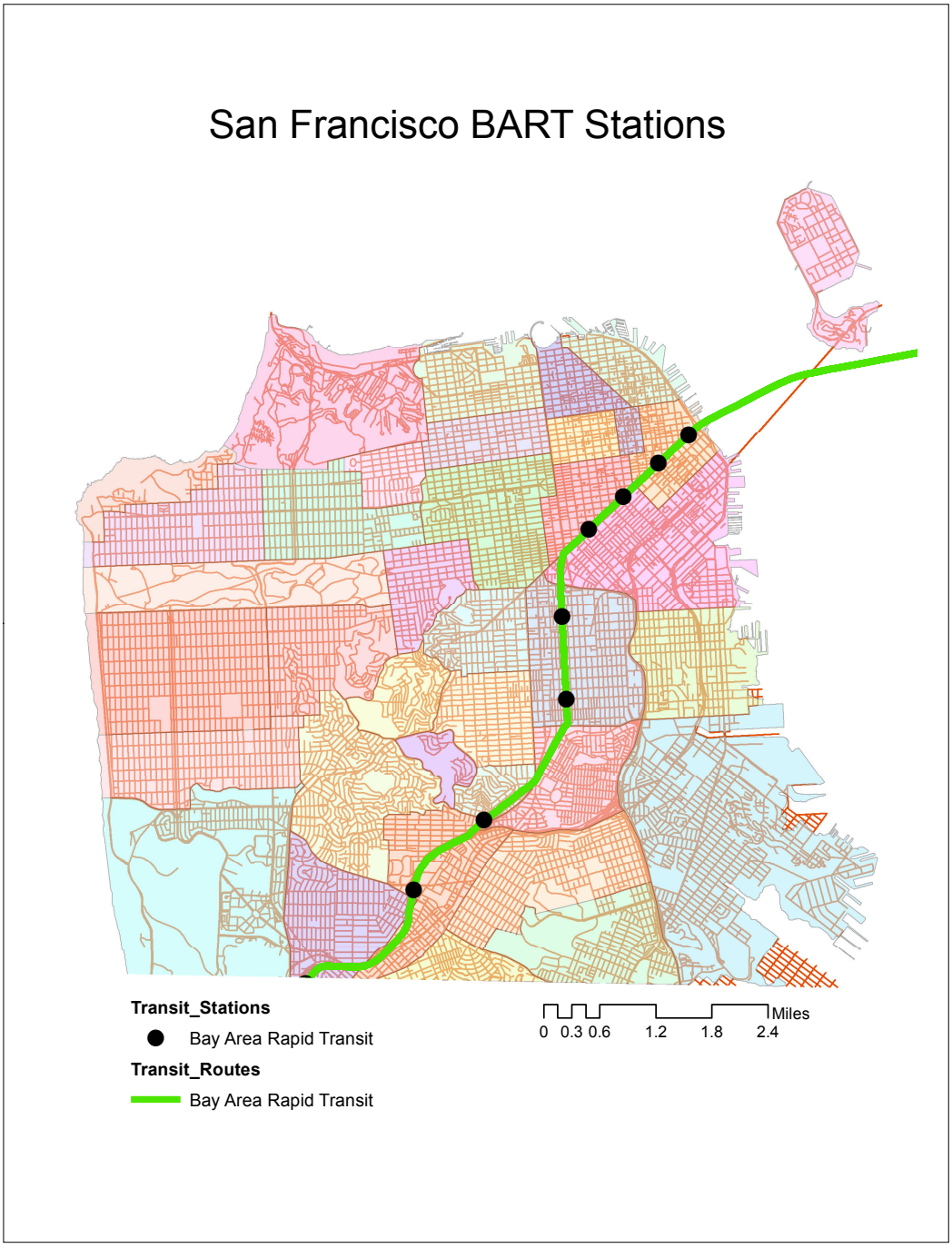
***Methodology**:* My methodology consists of constructing maps from a variety of statistical data sources that, in my opinion, are vitally important in deciding the placement of a new BART branch. It is important to note that I am looking both for locations for stations (which will be points on the map), and for a route for a new line (which will be a line on the map). While each of the maps individually suggests a new placement for BART, I ultimately combine them in an arithmetic manner in order to deduce the optimal placement of a new BART branch based on a variety of factors.

***Data sources and collection**:* The majority of my data comes from San Francisco Data, a site that makes a variety of local data, ranging from transit and zoning to crime and economics, available to the public. I also glean some data from National Atlas, a site that makes national GIS datasets publicly available, and the Sustainable Communities Index. Listing of data sets used in this project (unless otherwise indicated, dataset is from San Francisco Data):

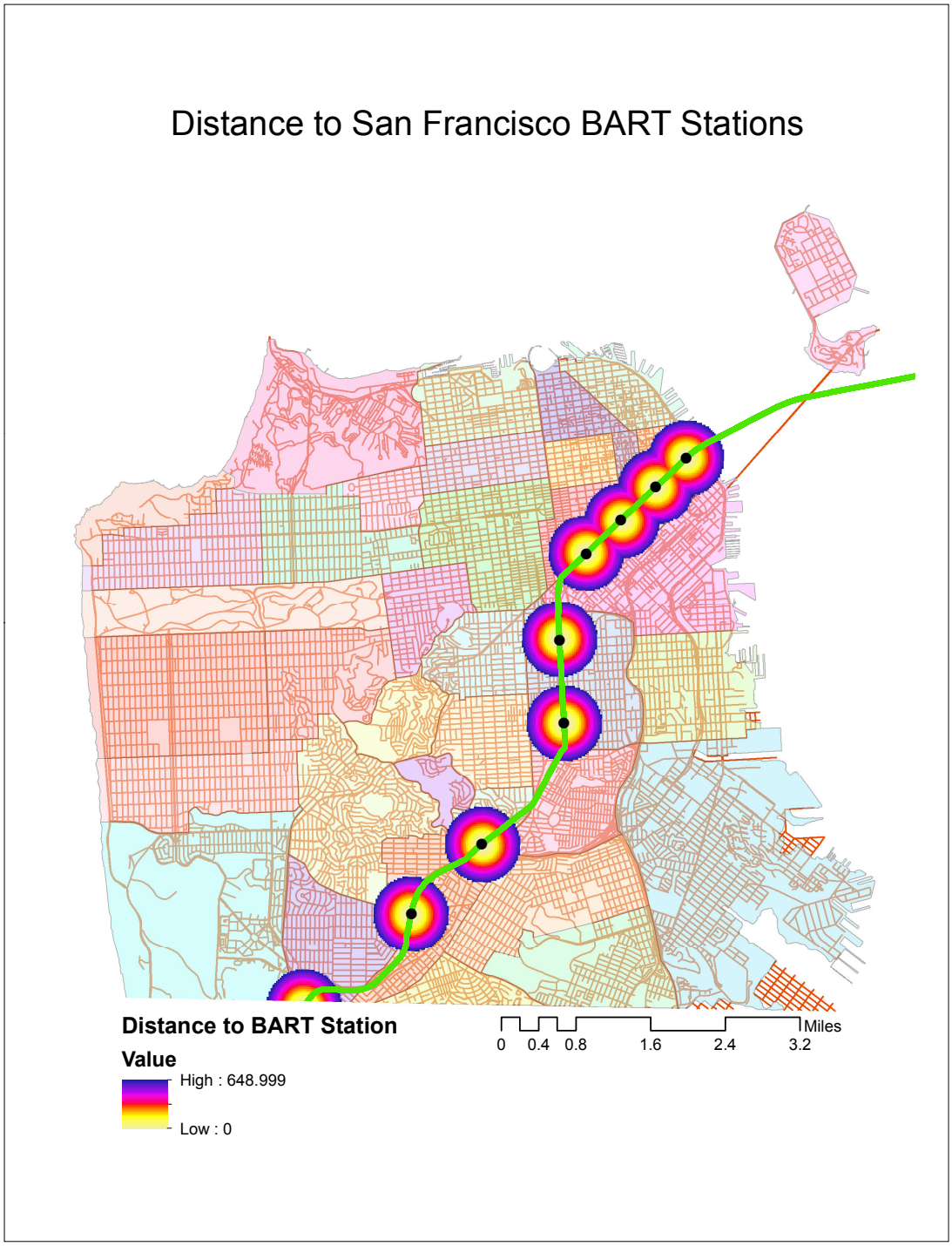
- Amtrak train stops and routes (National Altas)
- San Francisco streets basemap
- Physical elevation contours of San Francisco
- San Francisco planning neighborhoods
- San Francisco median income
- San Francisco population
- SF MTA Routes and Stops
- Transit Shapefiles (National Atlas)
- San Francisco Job density (Sustainable Communities Index)

***Maps**:* I developed a number of different maps that individually make an argument about optimizing placement of a new BART line. All of the maps use a shapefile of San Francisco streets as their base layer. Most maps also have a "planning neighborhoods" shapefile layered on top to give more contextual information. After developing these individuals presentations of different data, I eventually combine these maps in an arithmetic manner to develop a thorough conclusion.

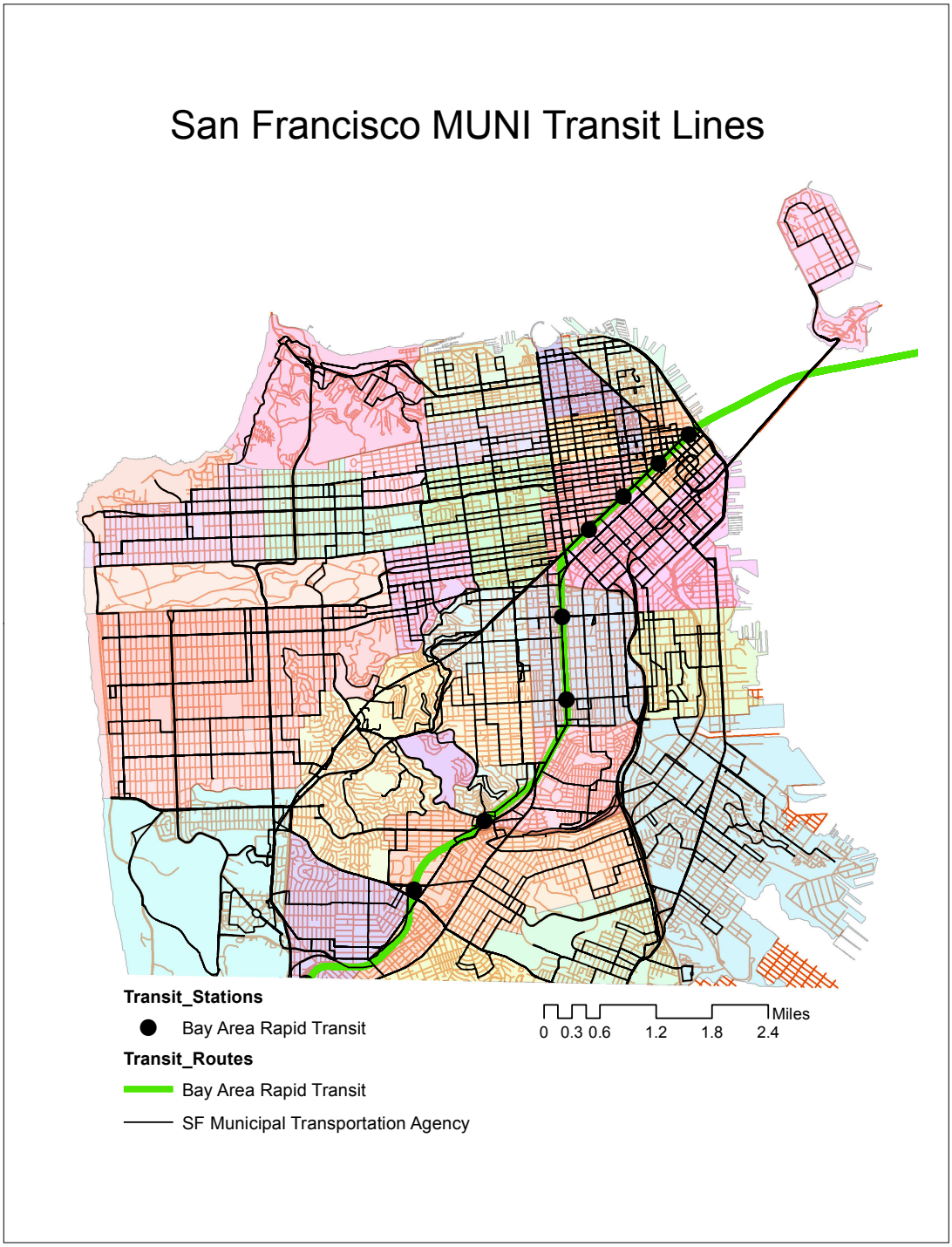
1. Current San Francisco BART Stations
    a. Method: For this map, I overlaid a simple shapefile of San Francisco streets with polygons indicating planning neighborhoods. Then, I added a layer of transit routes and a layer of transit stations. I used query builder on each of these layers so that the map only displayed BART stations and routes.
    b. Motivation: It is important to see the current extent of BART in the context of the maps I will be using in order to understand its shortcomings and thus, how it can be improved upon.



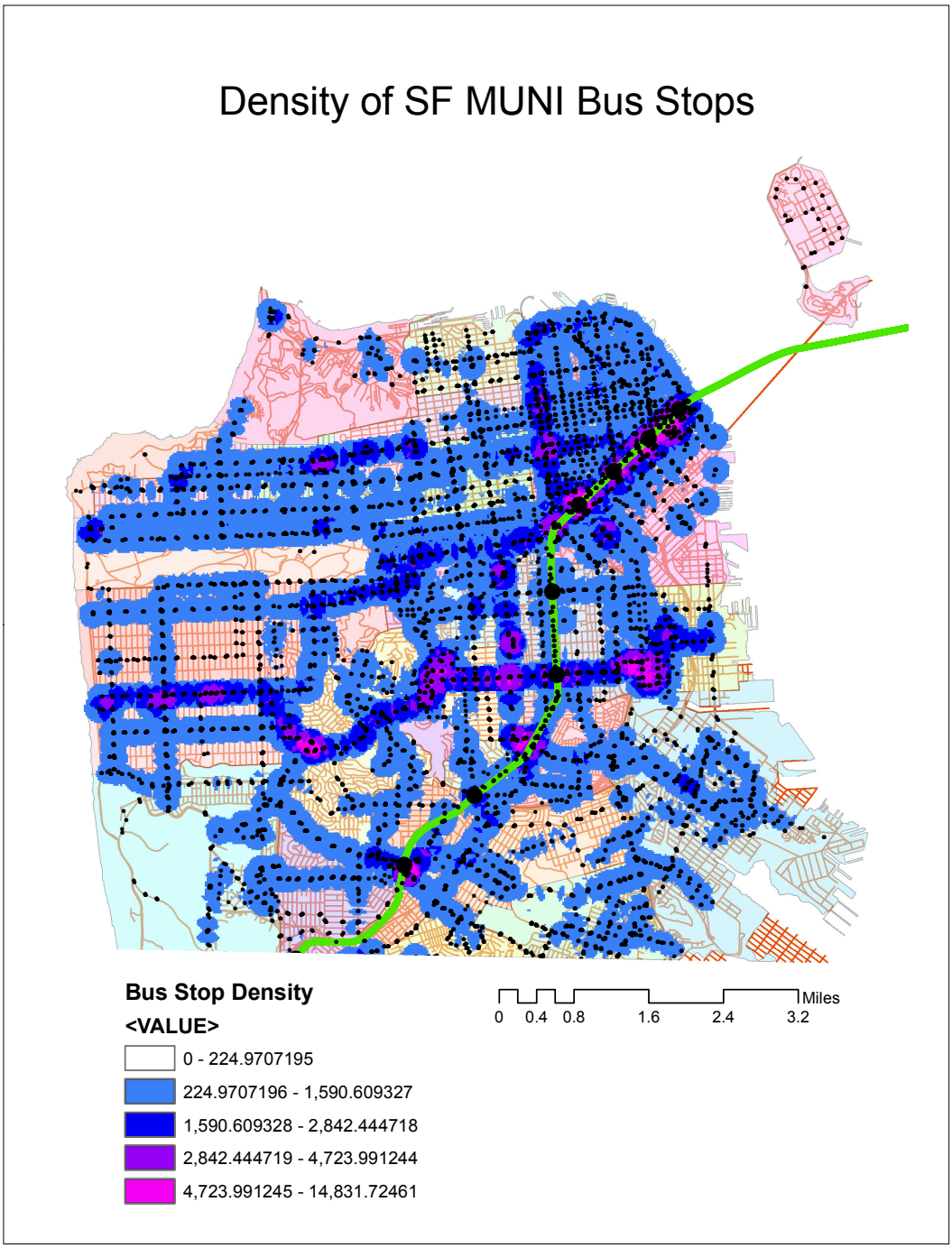
2. Distance to San Francisco BART Stations
    a. Method: Starting with Map 1, I used Euclidean distance to create a raster layer showing “bubbles” around the San Francisco BART stations indicating the surrounding area that could reasonably be reached by foot from a BART station.
    b. Motivation: As in Map 1, this map helps us understand the limited extent of BART in San Francisco in the stylistic framework we’ll be using throughout the project.



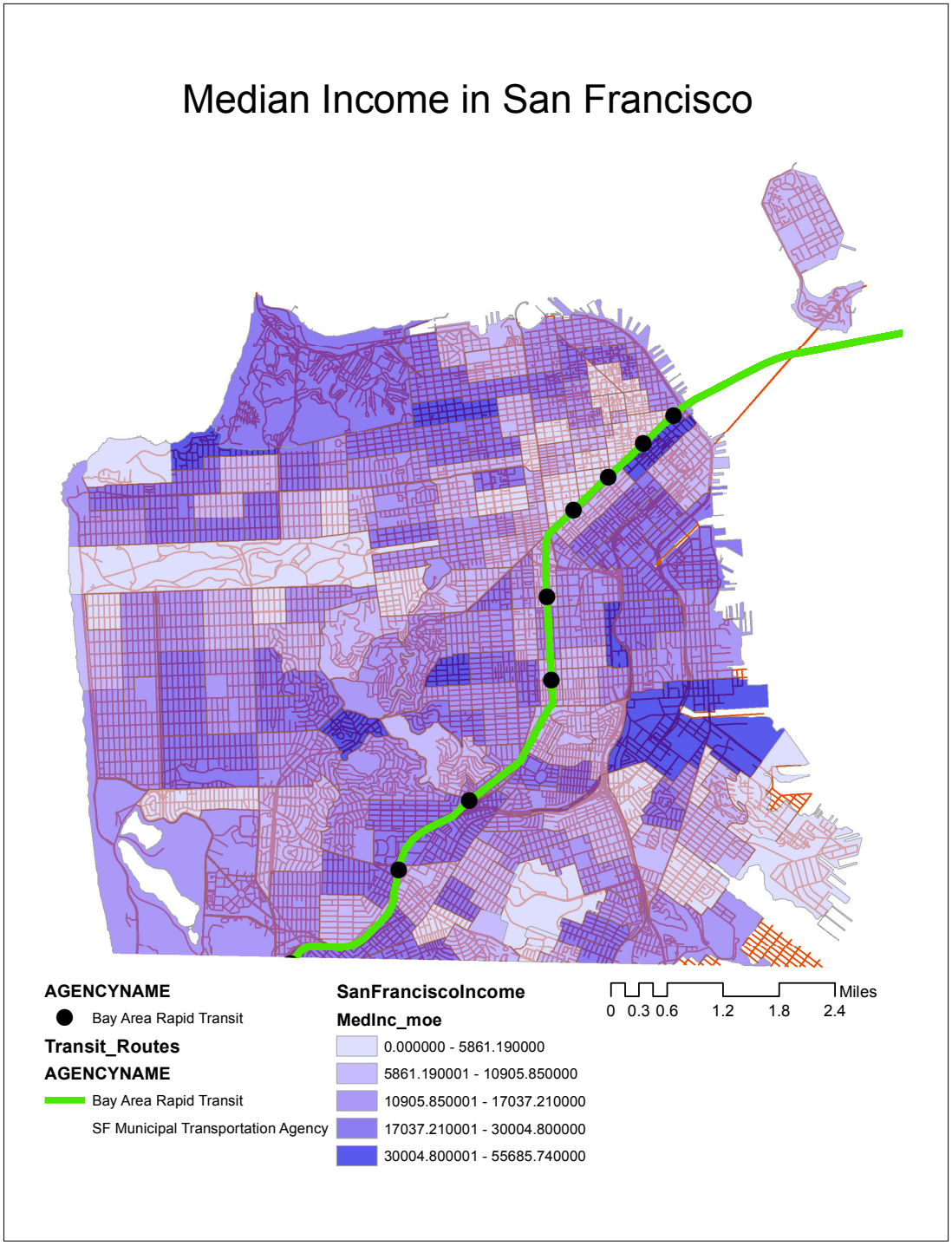
3. San Francisco MUNI Transit Lines
    a. Method: Starting from the base map, I simply added a shapefile with San Francisco transit lines. I used query builder so that they layer only displayed SF MUNI lines (SF MUNI is the San Francisco bus system).
    b. Motivation: One of the principal issues with BART is its clunky interface with other transit systems. By visualizing and working within the context of the MUNI system, my project aims to develop a more seamless connection between the two systems.



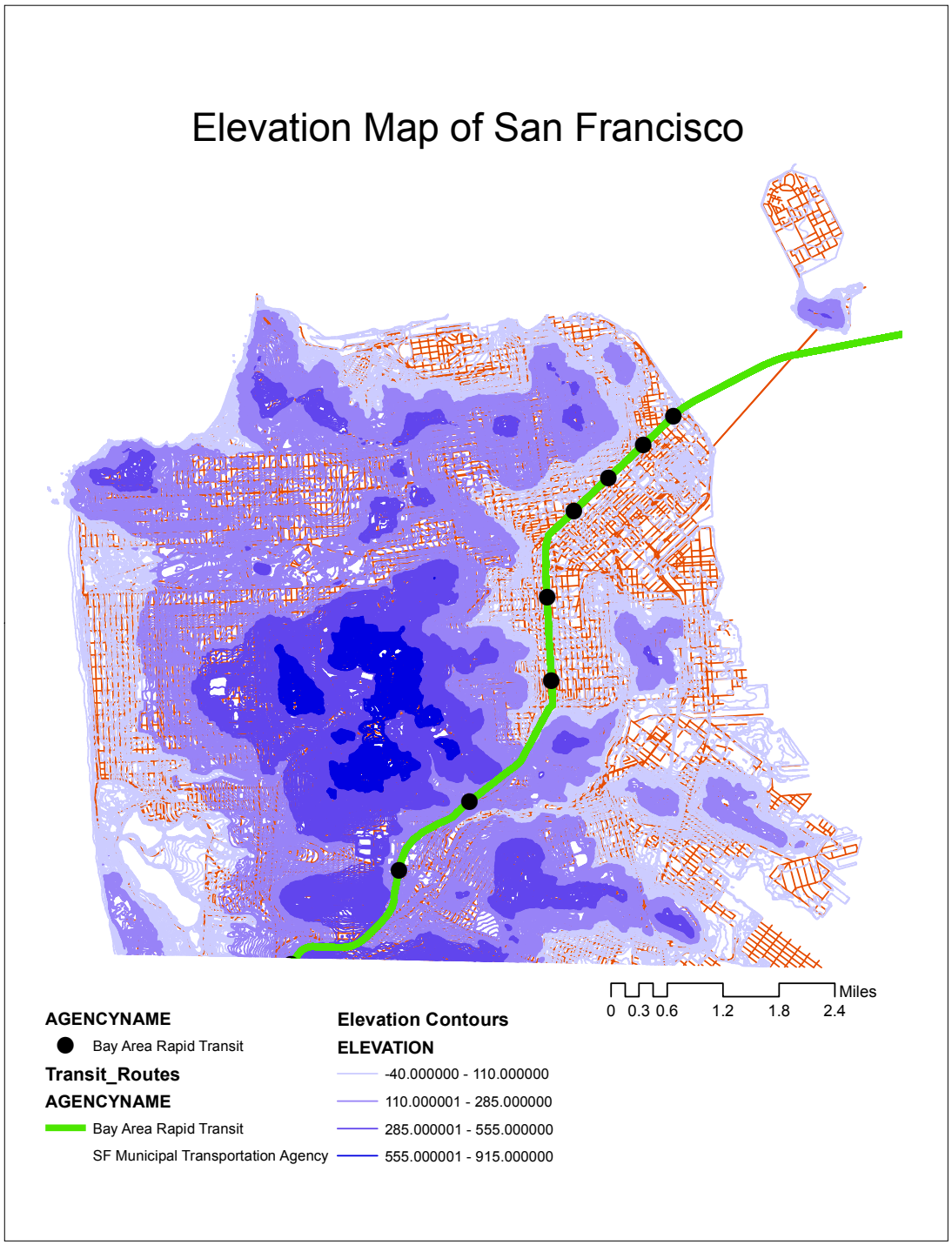
4. Density of SF MUNI Bus Stops
    a. Method: Starting from Map 3, I used Euclidean distance (with a small maximum distance) on the SF MUNI bus stop layer to show the density of SF MUNI stops.
    b. Motivation: This map will be instrumental in determining locations for both BART stations and lines that interface well with MUNI. Because MUNI is a notoriously slow and unreliable transit system, it may make sense to duplicate some of the major MUNI routes in order to improve service to those areas. It will be useful to place BART stations in MUNI station "hubs" (areas of high station density) to improve the connectivity of the systems.



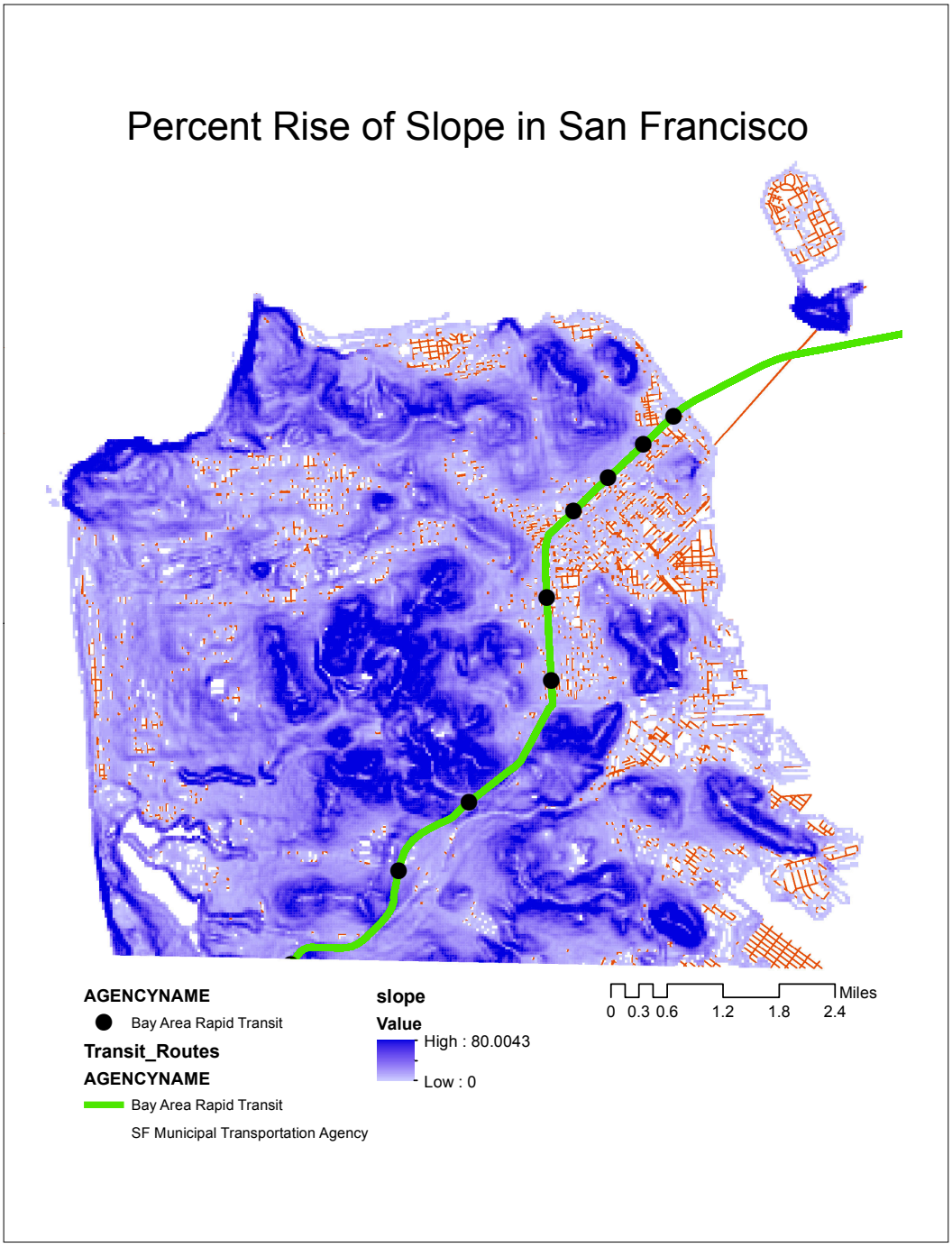
5. Median Income in San Francisco
    a. Method: I overlaid the base layer with a shapefile with information on median income in different census tracts.
    b. Motivation: I think a new BART line would have a more valuable impact serving lower income areas by reducing costs and wait time. Thus, this information will help me prioritize lower income areas over higher income areas.



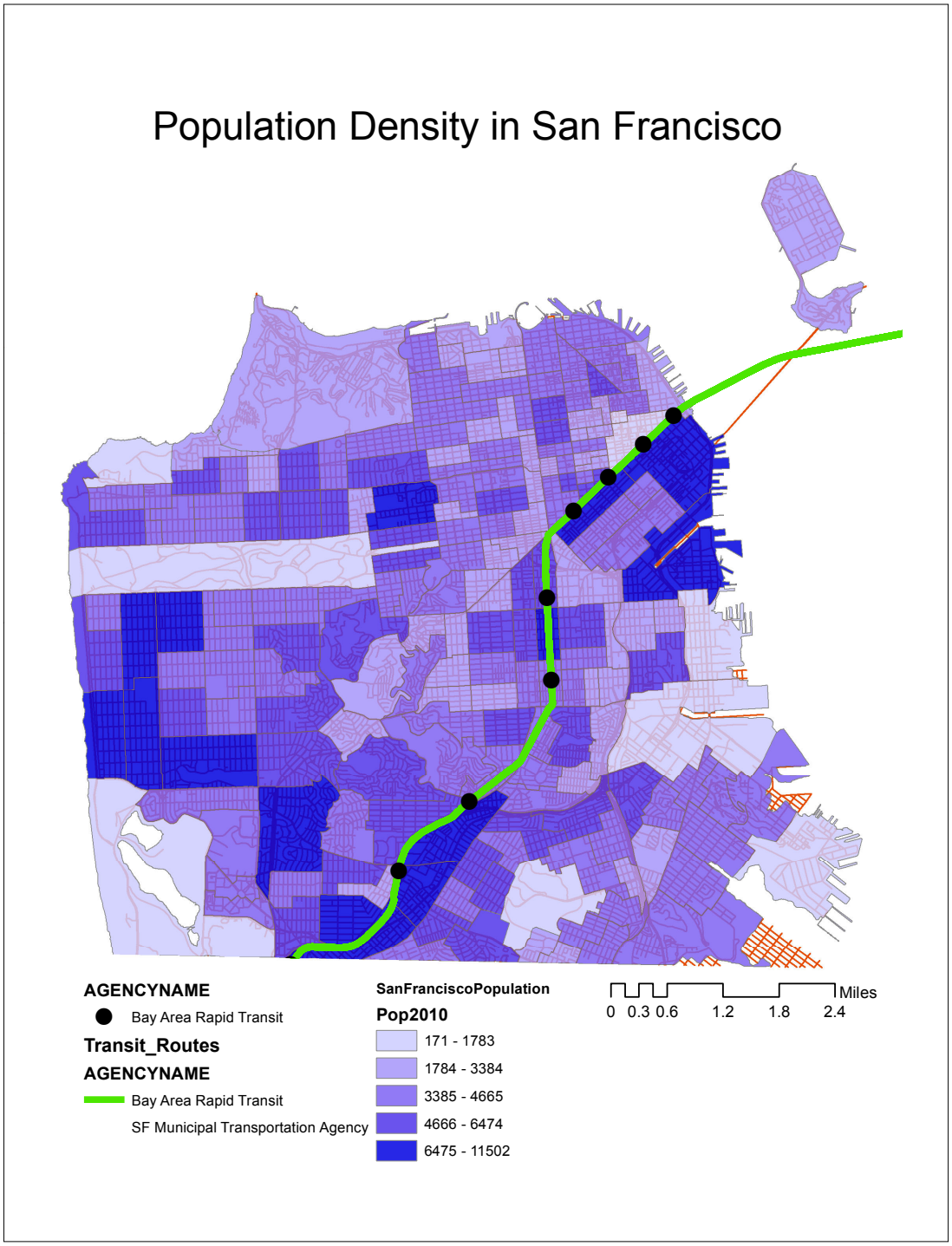
6. Elevation Map of San Francisco
    a. Method: I overlaid a shapefile of contours indicating the elevation of San Francisco on the basic basemap layer.
    b. Motivation: This topological map will help determine a proper geographic location for building a new line. An area with steep hills or abrupt elevation changes would not be suitable for such a project; this map will help establish those areas.



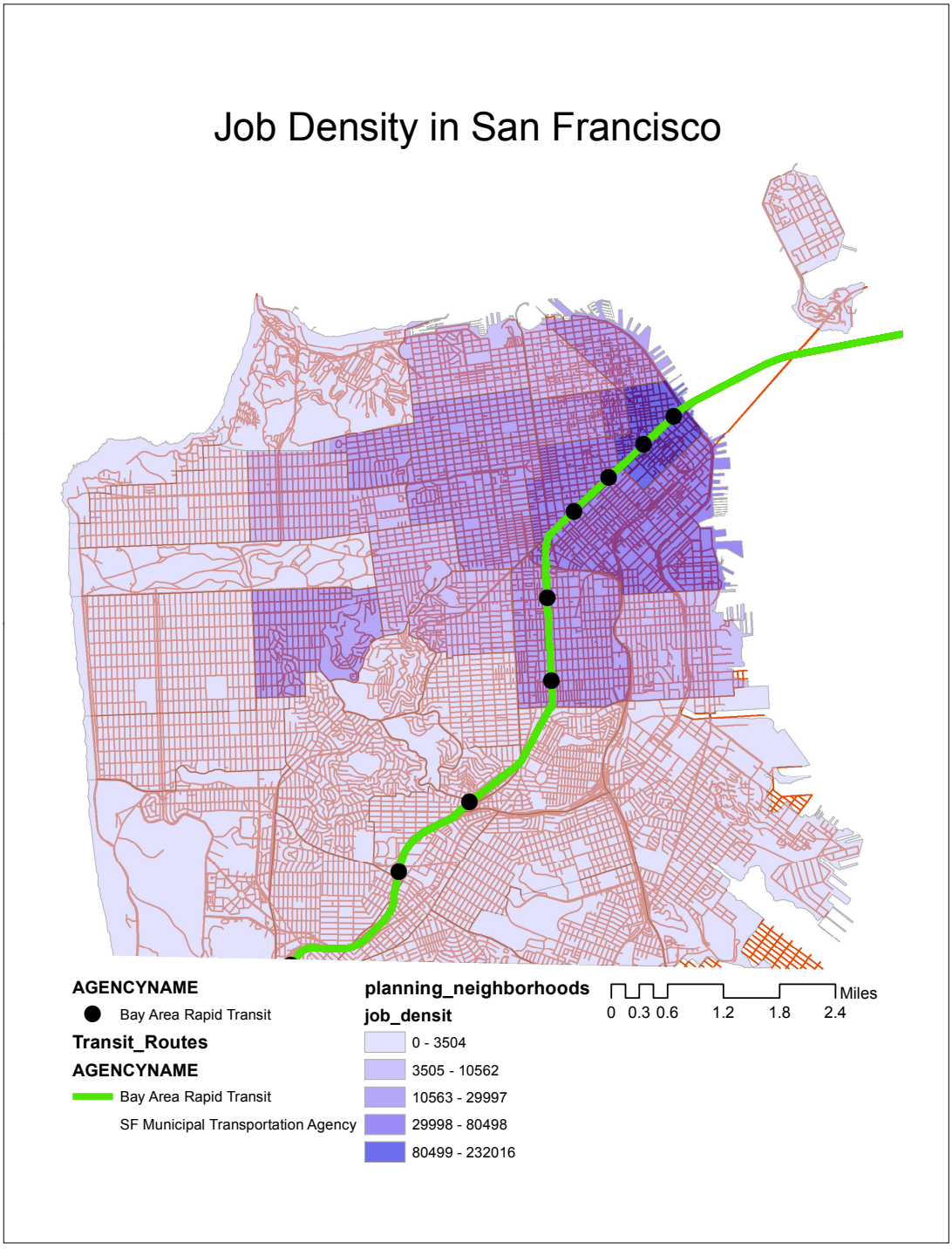
7. Percent Rise of Slope in San Francisco
    a. Method: Starting from Map 6, I used the slope tool to generate a raster grid indicating the percent change in slope at every point in the city. This map gives an idea of areas that are generally flat, versus areas that are generally steep (regardless of the elevation these areas may be at, although often steep areas are at higher elevations).
    b. Motivation: This map contains the essence of the topological information to be used in this study; in planning the new routes, I will prioritize relatively flatter regions over areas that are steep.



8. Population Density in San Francisco
    a. Method: I overlaid a shapefile with population per census tract on the basic basemap layer.
    b. Motivation: Constructing a new line that reaches areas of high density is of great importance, so that the costly and time-consuming effort of building a new subway line can serve the most people. This map will help me identify and prioritize those high density areas.



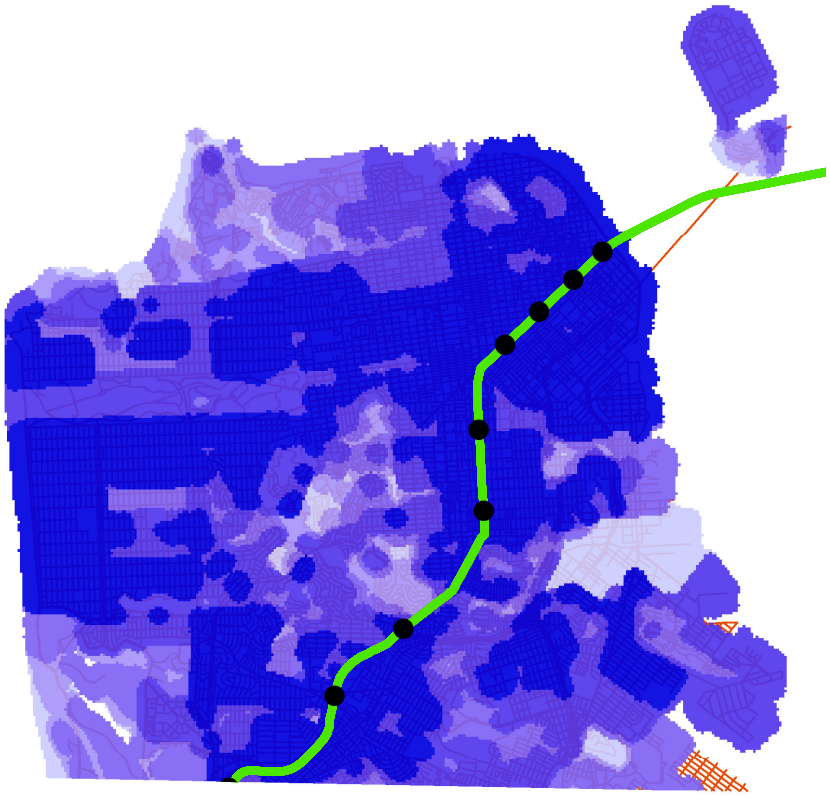
9. Job Density in San Francisco
    a. Method: Using data I collected online about the job density in different neighborhoods, I edited the attribute table of the “planning neighborhoods” layer. I then overlaid this layer on top of the basic basemap layer.
    b. Motivation: One of the primary objectives of public transportation is easing the challenges of commuting. By constructing a line that serves or reaches areas of high job density, the line is more likely to be of use to those with a daily commute.



***Map Algebra**:* Now that I had established the key factors in my investigation, I needed to combine them all mathematically to produce meaningful results.

- First, I needed to convert my data layers into workable datasets, so I converted job density, population density, and income distribution intro raster. Bus stop density and slope were already in raster form.
- Next I used the reclassify tool to normalize each of these layers to a common scale. I used a value of 1 or 2 to indicate an area (based on each layer) that would be favorable for a new BART line, and a value of 0 to indicate an area that would be prohibitive. The reclassification went as follows:
    - Bus stop density: 1 for areas of high bus stop density, 0 for areas of low density
    - Slope: 1 or 2 for areas of low slope, 0 for areas of high slope. (I also used focal statistics on my slope reclassification layer to iron our inconsistencies).
    - Job density: 1 or 2 for areas of high job density, 0 for areas of low density
    - Population density: 1 or 2 for areas of population density, 0 for areas of low density
    - Income distribution: 1 or 2 for areas of low/ medium income, 0 for areas of high income
- Finally, I combined all of these reclassified layers using Map Algebra to get a raster layer with values ranging from 0 to 9, ostensibly indicating the suitability of each location for a subway line. This layer is displayed on the following map (see next page).

Suitability for New BART Line



AGENCYNAME

Bay Area Rapid Transit

Transit_Routes

AGENCYNAME

Bay Area Rapid Transit

SF Municipal Transportation Agency

Suitability for New BART Line

<VALUE>

0.416666657 - 2.315789461

2.315789462 - 2.875

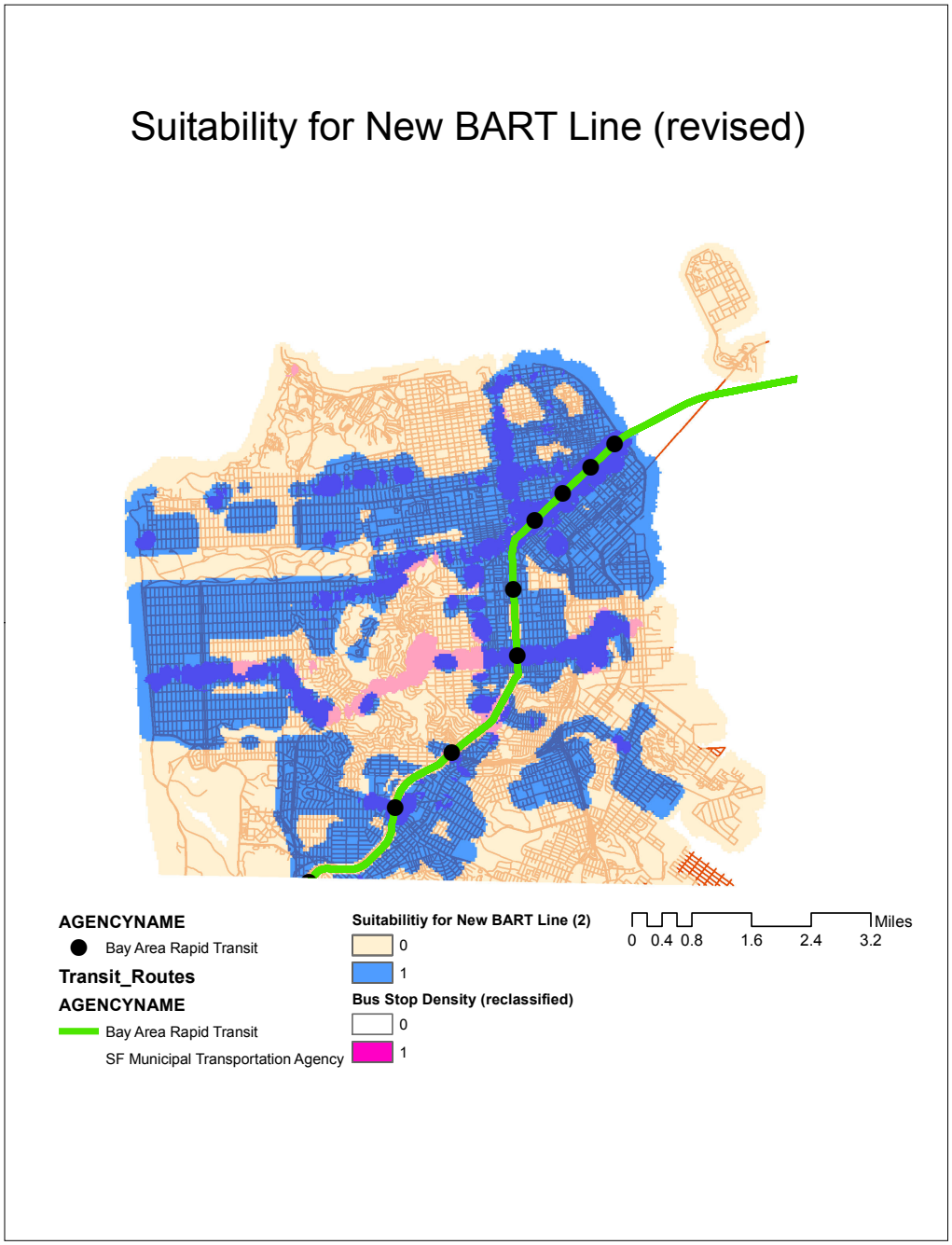
2.875000001 - 3.608695507

3.608695508 - 4.941176414

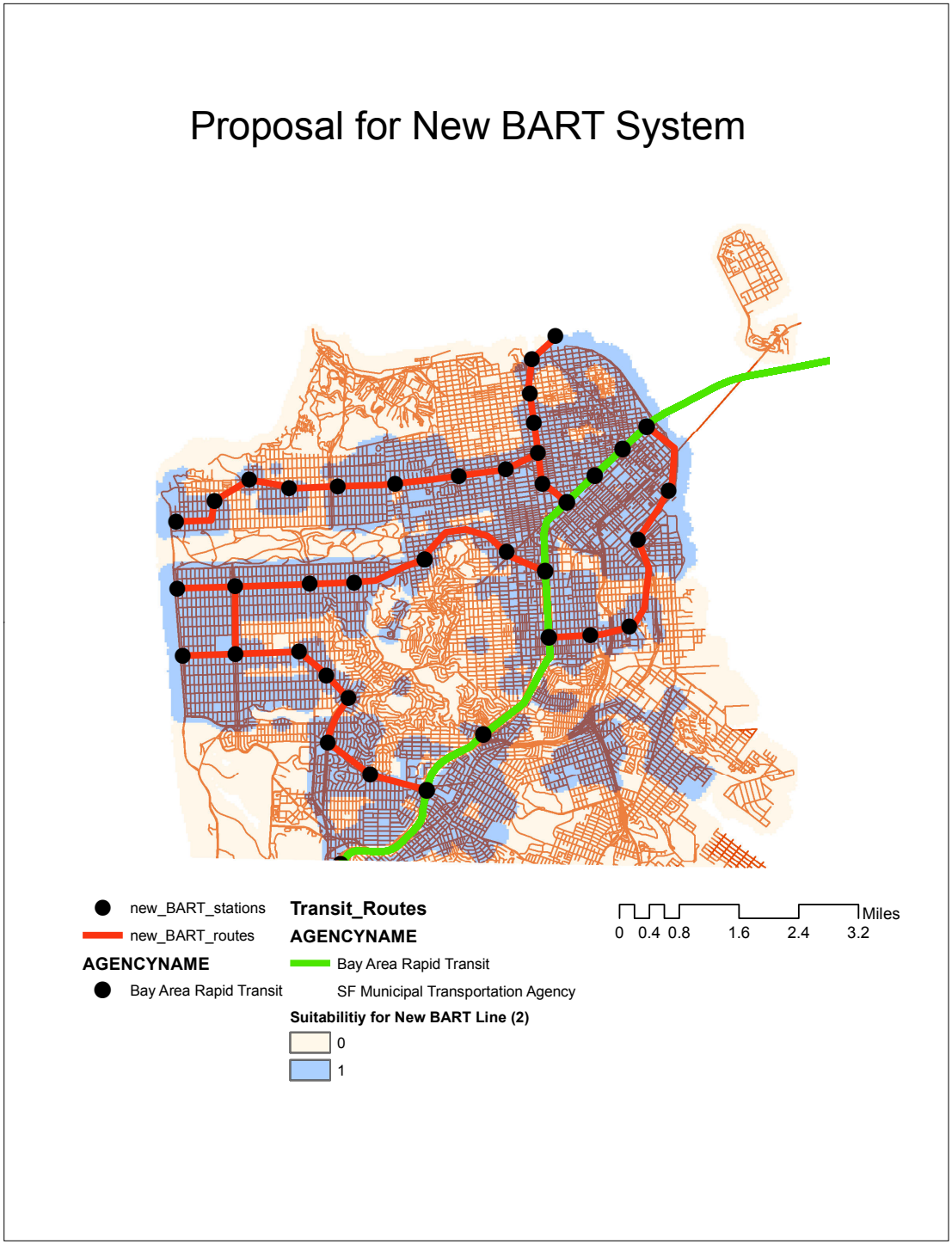
4.941176415 - 9

0 0.4 0.8 1.6 2.4 3.2 Miles

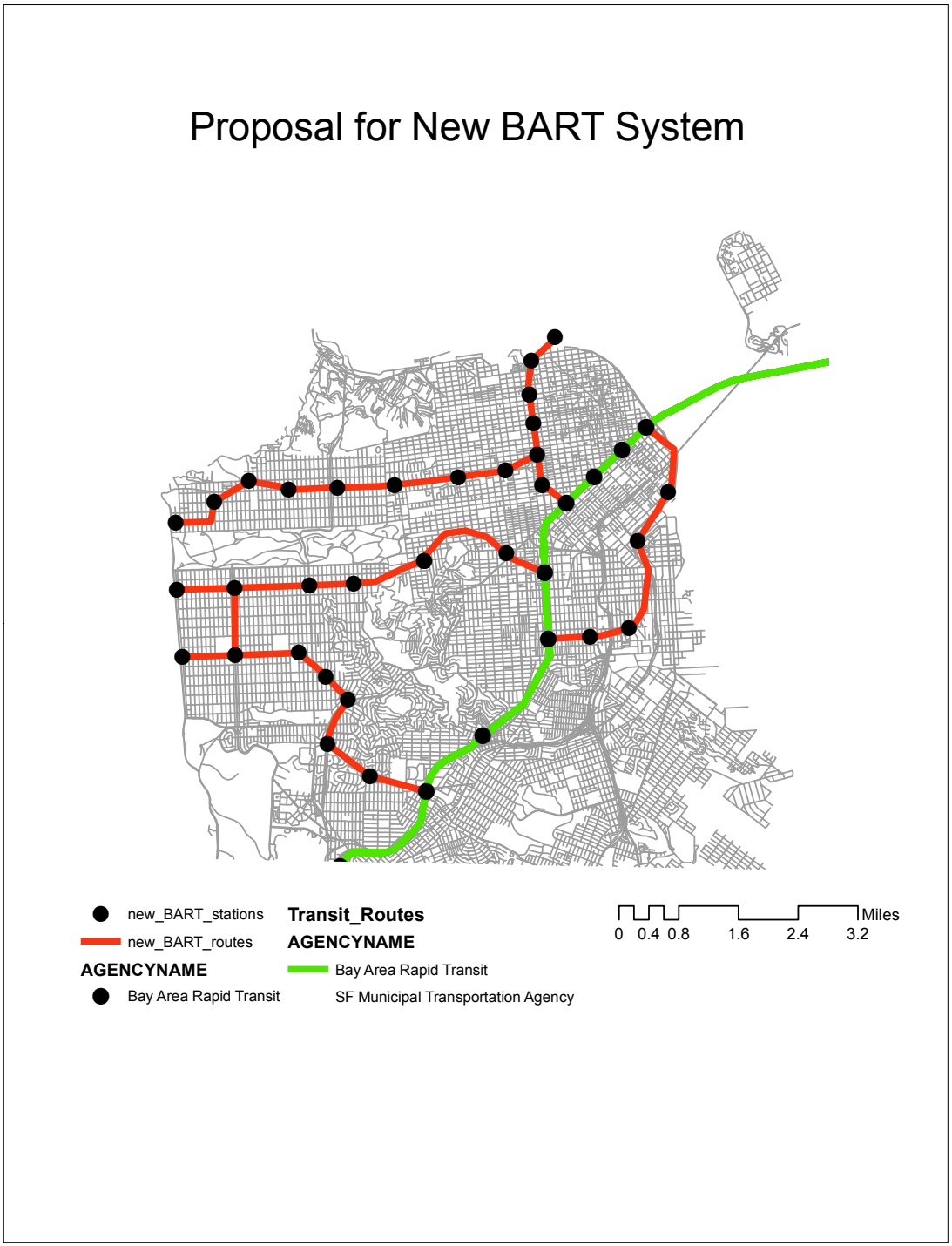
As is evident, the map does pick out some areas of suitability, which match up well with my casual notions of areas with high job and population density and low income, etc. However, I wanted to make my map more specific. First, I noticed that the area surrounding the existing BART line is very dark, indicating that that is an optimal area to place a BART line. While this fact was a nice confirmation of my methodology, there would be no need to add an additional BART line there. Instead, I converted the BART line to a raster layer. Then, I used map algebra again to *subtract* the BART line from the map above. Finally, in order to narrow the range of possible locations, I used reclassify on this suitability layer to pick only the very best areas, instead of accepting a broad range. These changes are reflected in the map below, which also includes the reclassified bus stop layer:



Feeling more confident with this suitability map, I hand-draw new shapefiles for new BART lines and new BART stations. The result of this step is a map, which follows, of a new potential BART system underlain with the suitability information:



Results and Conclusion: Based on my map analysis and calculations, I developed the following proposal (in map form) for an extension of the BART system within San Francisco:



My methodology was clearly imperfect and incomplete, as is likely to be expected in such a brief project. I encountered a number of limitations. One limitation was the fact that I approached this study from a mostly intuitive standpoint, instead of one grounded in urban planning paradigms. As a result, it is likely that I drew the wrong conclusions from some of my data, or simply omitted

factors that may have been relevant. I also encountered limitations in the specificity of the data I could find. Oftentimes, I was limited by the size of a census tract, which could have convoluting or counterproductive effects on my data. Another structural limitation of my project is the sheer difficulty of crafting an algorithm that would wrangle different factors into a cohesive product. For example, what I would really have wanted to craft is a system that linked areas of high population *to* areas of high job density. Instead, my algorithm equated these types of areas and hoped that their pull would equalize throughout the course of the process.

On the other hand, and despite these limitations, I feel my results are reasonably successful. Given my cultural knowledge of San Francisco, these lines (which I arrived at quantitatively), all resonate with my casual understanding of where people are trying to go within the city and where the pain points in the San Francisco transit system are. I was also pleased to see that my calculations identified the current San Francisco BART line as falling within an area of suitability. Finally, upon returning to the Coolidge map of the original plans for BART, simple observation confirms that my independent solution and the original BART plans are not wildly divergent.

I found this project to be a very constructive exercise. First and foremost, it allowed me to become well acquainted with ArcGIS mapping software, a relationship that was sometimes painful, but mostly useful. Second, by jumping into a complex transit-planning project, I quickly became aware of the challenges and ambiguities that make such work difficult and also exciting. Ultimately, it seems, there are many ways to craft a successful system; gathering the right data is only the first step. This data must be manipulated, aggregated, and interpreted, all of which require an inherently human touch. Data-driven urban planning is a great interest of mine, and I look forward to applying the skills and insights developed here to projects in the future.

Bibliography:

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