



# 2011

## Guidelines for Transit Bus Stop Spacing: Improving Accessibility and Performance



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# **Guidelines for Transit Bus Stop Spacing: Improving Accessibility and Performance**

## **Project Report**

Prepared for

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Cornelius Nuworsoo is the Principal Investigator. He prepared the study proposal, conducted day-to-day project management and coordination of all tasks, performed much of the analyses, wrote sections and compiled the study report. Anurag Pande is the co-investigator.

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### **Key Words**

Transit, stop spacing, GIS, catchment area, buffer, activity concentration, distance separation, planning

## **Summary**

### **The Study**

This research involved a comprehensive study of spacing standards in general and specifically the development of a procedure for selecting stop locations. The procedure is evaluated against sample routes in two case study locations.

One location is the transit-friendly city of San Francisco. It is selected to represent large urban environments with a central city type of density in the location of activities. It also provides variations in topographical characteristics.

The other location is San Luis Obispo County. It is selected to represent the small urban, suburban and rural types of environment. The County provides wide variations in the density of people and proximity to stop locations.

The study applied readily available demographic and economic data on corridors served by existing transit routes within these case study locations in the development of a systematic set of procedures for selecting stop locations. The outcome of the research is a simple tool with associated recommendations that transit operators and planners can adopt in: (a) consolidation or extension of existing routes or (b) planning for new routes.

### **Key Findings**

This study has provided additional confirmation of the potential benefits of properly defined stop spacing. The study applied knowledge from previous research to develop a simple tool for practical application by practitioners to realize the benefits of proper stop spacing whether in enhancing operations or in planning for future expansion.

It is an obvious notion that the more people who live or engage in other human activities close to transit stops, the more accessible the service would be to them and the higher the potential of using it. Many transit operators established several stops to realize this notion. However, for a given traffic and roadway condition, the more frequent stops are along a route the slower the route travel time due to deceleration, stopping and acceleration. So also the farther stops are from each other, the longer the average distances for access and egress. Early research revealed that the optimal spacing therefore is one that minimizes total travel time, which includes access and in-vehicle times.

Further research has shown that there are operating cost increases associated with close spacing and operating cost savings associated with wide spacing. The optimal spacing



therefore is one that minimizes total costs, which include travel time costs to transit users and operating costs to transit providers. Such an achievement would both improve operational efficiency and maintain good accessibility. Accessibility can be dealt with by guaranteeing that population concentrations are within acceptable walking distances to transit, which the literature places at a quarter to a half mile. Other provisions can also improve accessibility by accommodating those who would access the service by other modes. Some examples are bicycle parking for bicyclists, convenience of transfer for users of other transit service, and parking or drop-off locations for automobiles. If too large and not in a structure, automobile parking can occupy so much space as to extend the access distance for walkers and bicyclists. The preferred policy would be to concentrate activities and locate stops in such a way as to prioritize walk access

Research revealed that stop spacing is generally shorter in the US than other countries abroad, but transit use is higher in those places. In general, European cities recommend 3 to 4 stops per mile, or approximately 1300 feet of separation. American guidelines recommend stops between approximately 500 to 1300 feet of separation. While increasing stop spacing distances could increase walking distances for some users, in places with high transit stop density, most access distances will remain within the acceptability threshold of a five- to ten-minute walk. This study added confirmation to this observation. Studies have also shown that fewer stops will concentrate passengers at the remaining stops along the route, which can increase predictability, allow for a more accurate schedule, and result in a more reliable service. Concentrating passengers can also reduce the dwell time per passenger per stop, which leads to an overall reduction in route travel time. Reducing travel time reduces operating expenses which in turn could enable operators to provide more stop amenities. Reduced operating expenses may also translate into more frequent service. Ultimately, a more reliable service means passengers will spend less time waiting at bus stops.

This study has similarities with previous studies. It uses GIS data by census block but with uses population and employment data rather than ridership to represent the spatial distribution of potential demand. This distribution is used to determine both the efficiency in the alignment of routes and the preferred locations of stops. Thus it can serve as a tool in planning for existing settlements as well as future settlements when ridership data is not available. It is also similar to other studies that recognize the importance of accessibility to transit and the implications of cost for both riders and operators. It differs by not using mathematical programming, but is similar to simulation in the approach of using multiple criteria in a step-by-step approach to determining stop locations.

The procedure for stop spacing used in this study considers the factors most important to safeguard accessibility while enhancing performance. In a rough order of priority, the factors

are: locations of the highest concentrations of population and employment; transfer points; major service centers; and steep grade segments. Then a combination of adopted stop spacing and acceptable walking distance is used to fill in, eliminate or relocate other stops.

The appeal of this procedure lies in its simplicity. Input to the process is readily available. Block level data is obtainable by fine geographical area for population and employment from the US census. Instead of reliance on the decennial census, most recent data is available because of the American Community Survey and the data is easy to obtain from the Census LEHD online mapping application. Although it does not involve specific linear programming formulation, the procedure still encapsulates factors of user convenience and time costs as well as operator costs. These were termed in the literature operating and societal costs.

The application of this study procedure to the case study routes produced results that are consistent with findings in the literature. Key results of its application to the specific case study routes may be outlined as follows:

- a. Reduction in the number of stops by 10 percent to 44 percent;
- b. Reduction in buffer overlaps by 9 percentage points to 44 percentage points;
- c. Less than commensurate reduction in coverage area of 0 percent to 13 percent, which would mostly affect those on the fringes of the catchment areas of stops;
- d. Potential reductions in route travel time for all patrons ranging from 1 percent to 12 percent for the low estimate and from 3 percent to 32 percent for the high estimate.

## **Recommendations**

This study recommends widespread adoption of this methodology for routine application by transit planners and operators. As part of the adoption process a few specifics are pointed out. These are presented in four theme areas: spatial analysis framework; stop spacing distances; the step-by-step stop spacing procedure; and public input.

### **Spatial Analysis**

The geographical detail of spatial analysis is important in stop spacing. The literature postulates that estimates of public transit coverage based on census blocks have proven to be the most disaggregate and the most representative of the population served. The availability of census population and employment data at the block level facilitates spatial analysis with GIS at a detailed geographic scale rather than the macro level of the traditional travel analysis zones. The data also provide alternatives to estimates of ridership. Planners are well-served to conduct analysis at the census block level for which data is readily available.

Where tools permit, network distances (rather than Euclidean distances) should be used to demarcate catchment or coverage areas of stops. The availability of robust GIS software facilitates this type of spatial analysis.

### **Stop Spacing Standards**

There is general recognition that people are willing to walk ¼-mile to access human activities. If two adjacent stops have ¼-mile catchment areas, then the separation between them is two adjacent radii or ½-mile (2640 feet). This distance defines the upper limit of separation in adopted guidelines of operators for suburban environments. Use a half-mile separation as the target distance in built-up portions of small urban and suburban or rural areas.

There is the general tendency for most study results to prescribe shorter distances for dense urban areas than for more sparsely developed areas. Simulation results and guidelines from abroad all seem to point to approximately four stops per mile or ¼-mile separation (1320 feet) which would result in a non-overlapped catchment area radius of 1/8-mile per station. Use a quarter-mile separation as the target distance for densely built portions of large urbanized areas.

Vary these two target distances under two circumstances: (a) for “express” or “rapid” service, use two times the prevailing separation or ½-mile to a mile; (b) for steep segments of 10 percent grade or more use half the prevailing separation.

### **Stop Spacing Procedure**

The adopted stop spacing procedure should include consideration for multiple factors, such as proximity to concentrations of human activities, ready access to services, potential for transfers, topography and density of urban development. The latter dictates the target separation distance. The process in a nutshell is outlined as follows:

1. Identify population concentrations by census block using Census data for the latest available year. To do this, create a Raster map (or thematic map) of concentrations of people in a GIS software.
2. Identify major employment concentrations by census block using the latest available employment and shapefile data from Census LEHD website. To do this, create a Raster map (or thematic map) of concentrations of jobs in a GIS software.
3. For an existing route, add the existing transit route configuration and stops to the map.
4. For a new route, use the thematic maps to determine the general alignment for the route to connect high intensity centers.
5. Identify cross route locations for transfers and add them to the map
6. For an existing route, add a database of amenities (shelter, benches, route maps, etc.) present at individual stop locations and add them to the map. These can help in

determining stops to retain where choices need to be made between adjacent locations.

7. Identify primary stop locations from the previous steps.
8. Create buffers of 0.25-mile radius around the primary stops for most types of built environments and 0.125-mile radius for the dense urban environments.
9. For an existing route, use the buffers to determine where there is too much overlap so as to flag potential stops for elimination or re-positioning; in other areas, use the buffers to identify intermediate locations to achieve convenient, walkable access from nearby land uses.
10. For new routes, use the buffers to determine intermediate locations to achieve convenient, walkable access from nearby land uses.

### **Public Input**

Once the stop placement is completed, public input is desirable. First it would serve as a forum to inform the riding public or potential riders about the rationale for selecting stop locations. It would also help in choosing from alternative locations that are close to each other and in confirming transfer and connection points identified from data. Public input can help in determining which stop removals could have significant adverse impacts on such disadvantaged groups as the transit-dependent, elderly, or disabled. It can also help to identify issues that may be associated with the placement of certain stops.

### **Site-Specific Treatments**

Following the general demarcation of stop locations, site-specific adjustments and treatments may become necessary. These types of scenarios are dealt with in TCRP Report 19 (1996). They deal with issues related to the needs of passengers who would use the transit route, accessibility and appropriateness of the site for pedestrians, characteristics of the streets which the transit route traverses and placement near or far from intersections. The key issues and criteria are summarized in subsection 2.5 of the literature review.

# **1.0 Introduction**

## **1.1 The Study**

### **Overview**

This research involved a comprehensive study of spacing standards in general and specifically the development of a procedure for selecting stop locations. The procedure is evaluated against sample routes in two case study locations.

One location is the transit-friendly city of San Francisco. It is selected to represent large urban environments with a central city type of density in the location of activities. It also provides variations in topographical characteristics.

The other location is San Luis Obispo County. It is selected to represent the small urban, suburban and rural types of environment. The County provides wide variations in the density of people and proximity to stop locations.

The study applied readily available demographic and economic data on corridors served by existing transit routes within these case study locations in the development of a systematic set of procedures for selecting stop locations. The outcome of the research is a simple tool with associated recommendations that transit operators and planners can adopt in: (a) consolidation or extension of existing routes or (b) planning for new routes.

### **Objective**

The objective of this research is to develop a set of methodological and analytic procedures that could be easily applied by transit operators and planners in designating stops for new or existing bus routes. The purpose of such a procedure is to help improve accessibility to transit (via stops) and make it more convenient for users. In so doing the procedure can help improve the performance of transit operations and reduce costs for operators.

### **Method and Scope**

This study was approached as an applied research project. It combined review of the state of the art with the development of a hands-on procedure based on empirical data. The scope and method of the study may be outlined as follows:

### *Review of Literature*

The project involved a comprehensive review of published literature on stop spacing. The review also searched for distances people are willing to or typically do walk under various conditions of weather, topography and characteristics of the built environment. The objective of the review was to establish the state of the art in stop spacing from which to produce tables of comparative standards, guides and other relevant informational items. The review included information on transit systems in the US and abroad, especially Europe.

### *Collection of Data on Case Study Locations*

The study collected transit route system data from transit operators in the two case study locations. Transit system information and data were procured from the San Francisco Municipal Transportation Agency (SFMTA), San Luis Obispo Transit and the Regional Transit Authority (RTA) of San Luis Obispo County.

Data collected includes: (a) transit route network to identify general alignments of major intra-area and cross-area routes as well as key transfer points; (b) route profile data to identify high ridership points; (c) field inventory of stop locations to identify availability of amenities such as shelters, seats, rider information, etc.; and (d) major activity locations, that is, key origins and destinations such as major markets, employment centers, recreational spots and so on. All case study information was stored in a Geographic Information System (GIS). Other important information to help the analysis included point and shapefiles for case study locations on transit routes, road systems, topography and major activity centers.

### *Determination of Typical Catchment Areas for Transit Service*

The latest available census data on the case study locations were retrieved and linked to the GIS. The Longitudinal Employment and Household Dynamics (LEHD) data provided recent data on populations of residents and employees by census block. The data were used to determine concentrations of people and jobs by census block. Then buffers of walking distances were created to determine the catchment areas of existing or potential stop locations, which constitute the pool of potential users of public transit.

### *Development Location Selection Process*

A systematic process was developed for selecting stop locations. Details of the process are presented in Section 4.0, but depend on the following:

- Proximity to activity centers
- Connectivity with cross-routes
- Transferability to other modes or routes

- Acceptability of a threshold population within a catchment area to reach the location.

### *Evaluation of Associated Savings*

The location selection process was applied to the sample transit routes in the case study locations to determine improvements in the selections of stop locations. The operations under improved stop locations were evaluated in terms of reductions in dwell time, increases in average travel speed, reduction in fuel consumption and associated estimates of cost savings. A template was developed to aid the estimation of potential cost savings.

### *Synthesis for a Methodological Guide*

Findings from the literature and case study applications were used to establish a systematic procedure for selecting stop locations. Methods and processes developed and applied in the study were laid out systematically as a series of guided steps for the application of the procedure in locating bus stops. Analytic processes were captured into application templates to accompany the text on procedural steps.

## **1.2 Background and Problem**

Transit operators throughout the nation consider stop spacing in addressing such issues as increasing bus reliability and reducing travel times along routes. One factor that affects route travel time is dwell time at stops to allow for passenger boardings and alightings. Another factor is the frequency of bus stops. If a bus stops less frequently, there will be fewer dwell times and less time spent accelerating and decelerating leading to reduced fuel consumption. Concentrating passengers at few stops makes boarding faster per passenger over the course of the route as well as passenger loads more predictable (Curitiba, 2003). Greater predictability can lead to greater accuracy in scheduling and ideally, greater reliability of the service. Reliability and schedule adherence are both factors which make the system easy for transit riders to use. Any savings achieved due to travel time reduction or reduced maintenance from less acceleration or deceleration can be reinvested in the system in many forms. Savings can be spent on enhancing bus stop amenities at the stop locations which can provide better customer information as well as better stop design to allow for faster, easier, and safer boarding. Savings due to decreased travel time can be translated into increased frequency along the route. Having adequate bus frequency to serve the passenger demand along a route is linked to reliability. Any buses which may not be needed due to decreased travel times can be used as back-up buses to allow the agency to respond more quickly when a bus breaks down during service. These widely-held notions indicate that there are potential benefits from optimal stop spacing.

Stop spacing goes far beyond a specification for only distance separation for stops. TCRP Report 19 lists several other criteria that may be considered in the decision on where to place stops, but there is no established methodological process of determining the frequency and location of stops. US cities adopt standards based on those adopted elsewhere and perceived suitability for their own conditions. This is done by either a committee or a team and findings are presented as informational documents. This research is proposed therefore to establish a methodological process for identifying stop locations as a function of factors such as distance to adjacent stops, population and employment within catchment, which are indicators of potential ridership, proximity to activity centers and transfer points with public input to determine or confirm preferences for certain key locations.

### **1.3 Organization of Report**

This report is organized into nine sections. This first introductory section is followed by a survey of the literature on stop-spacing research, the importance of optimal stop spacing and the use of GIS in planning public transit. This section provides justification for the factors applied in the procedure of this study and explains its differences from other work.

The third section introduces the case study locations; it also explains why they are chosen. The fourth section lays out the concept and illustration of this study's procedure for stop spacing.

The fifth section presents application results of the procedure to a small urban area route. The sixth section presents application results to suburban and rural case study routes. The seventh section similarly presents results of the procedure to case study routes in a large urban environment.

The eighth section presents an overview of potential travel time and cost benefits of improving stop spacing along the case study routes. The final section offers concluding observations and recommendations.



## **2.0 Review of Literature**

### **2.1 Stop Spacing Research**

There is a wealth of research on stop spacing covering theoretical concepts, optimization, simulation and empirical studies. Vuchic and Newell (1968) studied stop spacing analytically as a trade-off between access to transit and in-vehicle travel time. Close spacing of stops would reduce access time to transit, but would lead to increased, in-vehicle travel time since the vehicle has to make many more stops. The authors showed that stops should be spaced more closely as demand increases, meaning, as density of the built environment increases, but stops should be further apart as the number of passengers on board increases. The optimal spacing would therefore be the point where marginal change in users' access time equaled the marginal change in their in-vehicle time. The results supported the notion that stops for larger capacity vehicles that are carrying high loads of passengers, such as trains, should be more widely spaced than those for smaller vehicles.

Other authors broadened the scope of stop spacing to include associated costs. Wirasinghe and Ghoneim (1981) defined optimal spacing in terms of minimizing the costs associated with passenger access and egress, in-vehicle time, transit vehicle operation, the building of stops and the maintenance of stops. These considerations resulted in greater distances between stops than considerations based on the minimization of passenger travel time.

Van Nes and Bovy (2000) derived optimal stop spacing distances for a large city and a small city in the Netherlands based on passenger travel times (access, wait, and in-vehicle) plus costs and revenues to the transit operators. The authors applied simulation to derive optimal stop spacing distances for scenarios that included minimization of passenger travel time and minimization of costs to both passengers and operators. They derived the optimal stop spacing of approximately 1970 feet (600 meters) for the small city and approximately 2625 feet (800 meters) for the large city.

Furth and Rahbee (2000) used a combination of historic ridership data and geographic information systems (GIS) data on a heavily patronized route within the Massachusetts Bay Transportation Authority's (MBTA) transit system in a dynamic programming model to determine the optimal number and location of bus stops for the route. The authors allocated the number of boardings and alightings at various stops to parcels in the corridor to represent the spatial distribution of demand in the corridor. With assumed values of time for walking and riding the bus, operating costs and other operational factors, the authors applied the dynamic programming to determine the number and location of stops that minimized time costs for

riders and operating costs for MBTA. The findings resulted in a reduction of the number of stops by approximately half from 37 to 19 including the relocation of several of the stops. The study discovered the need to double stop spacing from about 650 feet (200 meters) to about 1300 feet (400 meters).

This study has similarities with the MBTA study. It uses GIS data by census block rather than parcels but replaces historical ridership data with population and employment data to represent the spatial distribution of potential demand. This distribution is used to determine both the efficiency in the alignment of routes and the preferred locations of stops. Thus it can serve as a tool in planning for existing settlements as well as future settlements when ridership data is not available. It is also similar to other studies that recognize the importance of accessibility to transit and the implications of cost for both riders and operators. It differs by not using mathematical programming, but is similar to simulation in the approach of using multiple criteria in a step-by-step approach to determining stop locations.

## **2.2 Impacts of Stop Spacing**



It is evident from the literature that previous studies of stop spacing in terms of mathematical programming, optimization and simulation of operations have yielded much valuable insight into the benefits of optimal stop spacing. The study of the MBTA route by Furth and Rahbee (2000), for instance revealed such pertinent findings from a doubling in stop spacing as: (a) a slight increase of 0.60 minutes in the average walking time for passengers but with a more than commensurate reduction in the average in-vehicle travel time 1.8 minutes; (b) decline in average vehicle running time by 4.3 minutes; and (c) as a result, an estimated amount of \$132 per hour in the combined savings to passengers and the MBTA. Saka (2001) related the improvements in operating speed from reduced stop spacing into reduction in fleet size and savings in capital costs.

El-Geneidy et al (2005) provided further confirmation with the study of bus reliability and travel time in the TriMet system of Portland, Oregon. To test the hypothesis that stop consolidation for fewer stops would concentrate passengers, reduce travel times and increase reliability, the authors divided route segments into two groups for the study: the “treated” segments had stop consolidation, and the “control” segments remained unchanged. The report shows that overall, the theory of concentrating passengers did decrease the overall running time, and did not reduce the number of passengers. Running times on the “treated” segments declined by between two and nine percent. The report also noted that running times could have been further reduced from what results indicated if schedules, which were adjusted to accommodate the stop consolidation, had been adjusted sufficiently. The report estimated that

the elimination of each stop reduced running time by 42.2 seconds. The study did not find, however, that stop consolidation increased reliability, though this could be due to inadequate adjustments to schedules. However, previous studies have shown that boarding or dwell time could have an effect on the reliability of service (Turnquist, 1981). Kittleson & Associates (2006) identified such factors as the number of stops made to serve passengers and the number of left turns on public streets as significant variables that affect route travel time.

Figure 2-1 captures a summary of the trade-offs in placing stops closer together or farther apart (TRCP Report 19, 1996). The diagrams associated with the summary show that increasing spacing within reason could still maintain attractive walking distances to transit stops. This concept is relied upon heavily in the procedures developed under this study.

**Figure 2-1: Illustrative Trade-offs in Stop Spacing**

<p><b>Condition:</b> Bus stops approximately 800 ft. apart with 1/8 mile access zones</p>	<p><b>Condition:</b> Bus stops approximately 1200 ft. apart with 1/8 mile access zones</p>
	
<p><b>Close stops (every block or 1/8 to 1/4 mile)</b></p> <ul style="list-style-type: none"> <li>Short walking distances</li> <li>More frequent stops</li> <li>Slower bus speeds</li> <li>Longer bus trips</li> </ul>	<p><b>Stops farther apart</b></p> <ul style="list-style-type: none"> <li>Longer walking distances</li> <li>More infrequent stops</li> <li>Higher bus speeds</li> <li>Shorter bus trips</li> </ul>

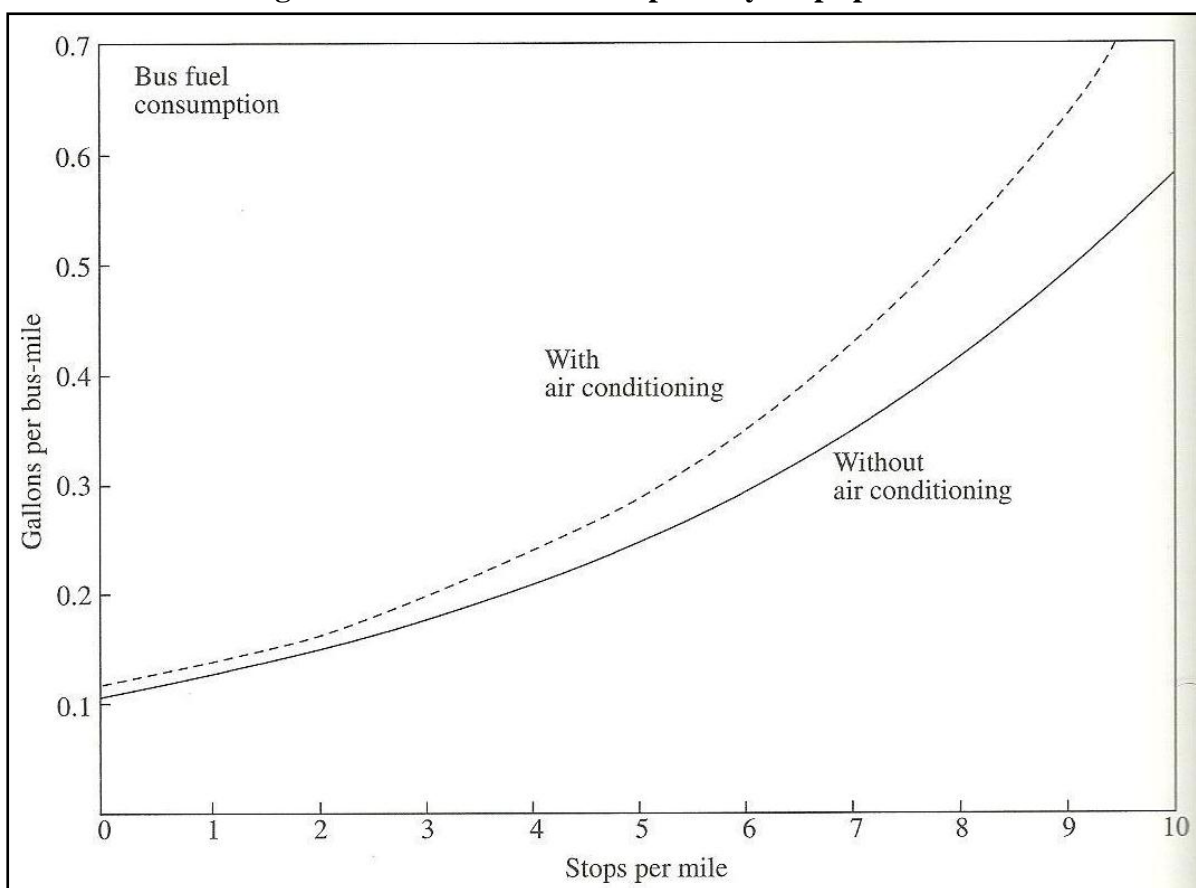
Sources: Text from TRCP Report 19 (1996)

### 2.3 Operator Benefits of Optimal Stop Spacing

The literature reveals certain benefits to transit operators with optimized stop spacing. Generally, the Federal Highway Administration (2009) recognizes that aggressive driving increases the fuel consumption of a vehicle. Aggressive driving is defined as accelerating and decelerating repeatedly. Though bus drivers are not necessarily aggressive, they must accelerate and decelerate for each bus stop. Vuchic (2007:139) states that “acceleration consumes most of the energy used in travel.” Figure 2-2 is a graph of the increase in fuel consumption as stop spacing decreases. There is also data showing that vehicles get their best

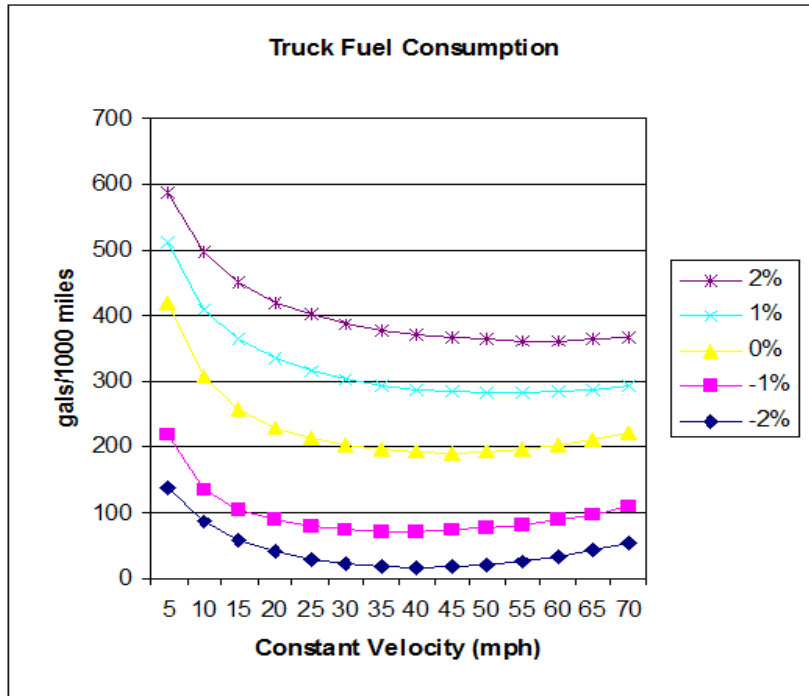
gas mileage at mid-range speeds, as opposed to driving very slowly or very fast (US DOE, 2009). Research also shows that for cars and trucks, fuel consumption, oil consumption, and vehicle depreciation are based on the constant velocity of the vehicle (TTI, 1990). Figure 2-3 shows the change in fuel consumption as a function of velocity. Consumption of fuel, oil, and tires are all reduced as speed increases, and reductions are especially significant for each unit increase in mph at very low speeds. For trucks on flat terrain, an increase from 10 mph to 15 mph reduces fuel consumption by roughly 50 gallons per 1,000 miles. The same increase in speed reduces oil consumption by 10 quarts per 1,000 miles. Figure 2-4 illustrate the decrease in truck oil consumption as a function of velocity.

**Figure 2-2: Bus Fuel Consumption by Stops per mile**



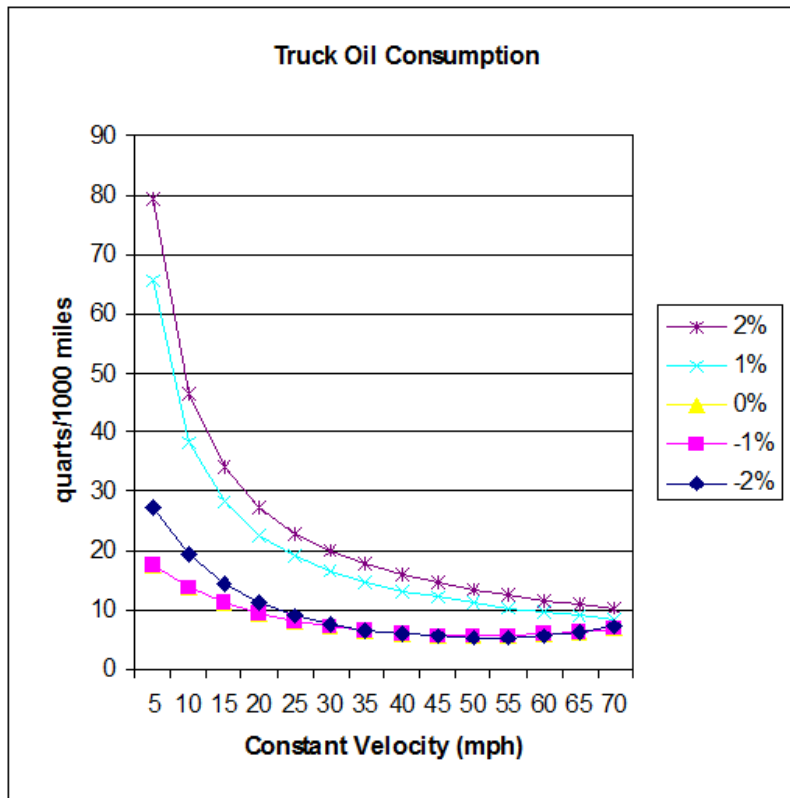
Source: Raus, 1981 in Vuchic 2007

**Figure 2-3: Truck Fuel Consumption vs. Velocity**



Source: Texas Transportation Institute, 1990

**Figure 2-4: Truck Oil Consumption vs. Velocity**



Source: Texas Transportation Institute, 1990

## 2.4 Stop Spacing Standards

A few transit agencies in the US developed stop spacing standards in recent decades: AC Transit (1989); TriMet (1989); Municipality of Metropolitan Seattle (1991); Chicago Transit Authority (2001); SFMTA (2009a). These efforts are in part attempts to replicate the successes that European cities have had in capturing high transit mode shares. The standards act as guidelines for agencies to determine where stops are needed or where consolidation is needed. Table 2-1 illustrates the wide variability in stop spacing among selected US cities. The table also reveals the varied standards applied within the network of each operator.

Table 2-1: Stop Spacing Guides of Selected US Operators

Location (Operator)	Conditions	Stop Spacing (feet)	Stops per Mile
San Francisco (SFMTA Proposed)	Grade below 10%	900 to 1400	<i>3 to 6</i>
	Grade above 10%	500 (minimum)	10
Portland (TriMet)	Dense area (22units/acre)	780	<i>6 to 7</i>
	(4 to 22 units/acre)	1000	5
Seattle (King County Transit)	Local	<i>880 to 1320*</i>	4 to 6
	Other	<i>660* (maximum)</i>	8 (maximum)
	Other	500 (minimum)	10
San Bernardino (Omnitrans)	CBD	1000	5
	High to Medium Density	750 to 900	<i>5 to 7</i>
	Medium to Low Density	900 to 1300	<i>4 to 5</i>
Chicago (Chicago Transit Authority [CTA])	Local	<i>660 * (every 1/8 mile)</i>	8
	Local	1320 (maximum)	
	Express	2640 to 5280 (½ to 1 mile)	<i>1 to 2</i>
Alameda County (AC Transit)	Local	800 to 1300	<i>4 to 7</i>
	Rapid	1700 to 5000	<i>1 to 3</i>

Sources: AC Transit (1989); CTA (2001); SFMTA (2009a); TriMet (1989); Seattle (1991).

\*Note: Italicized values are conversions based on the published guidelines; other values are as given.

TCRP Report 19 (TTI, 1996) summarizes typical stop spacing based on the type of environment or density of an area. The spacing ranges in Table 2-2 indicate that there is a wide variation in stop spacing standards among US cities with shorter spacing in more densely built areas than lower density areas. The summary reveals that typical spacing could be two times as long in suburban and rural communities as in dense urban communities. This explains why this study looked at case locations in different types of urbanized areas.

Table 2-2: Summary of Typical Stop Spacing in the US

Built Environment	Spacing Range		Typical Spacing	
	Length (feet)	Stops per Mile	Length (feet)	Stops per Mile
Central Business Districts	300 – 1000	5 – 18	600	9
Urban Areas	500 – 1200	4 – 11	750	7
Suburban Areas	600 – 2500	2 – 9	1000	5
Rural Areas	650 – 2640	2 – 8	1250	4

Source: TCRP Report 19 (TTI, 1996)

The literature also reveals slightly wider spacing abroad than in the US. According to El-Geneidy et al, (2005), “Furth and Rahbee (2000) observe that stops in northern European cities are spaced much further apart than in comparable US settings, yet the European transit systems are still able to capture a greater share of the urban travel market. Reilly (1997) also found that the common European practice was to space stops at 3 to 4 per mile (*as in Table 2-3*) compared to the U.S. practice of 7 to 10 per mile” (*as in Table 2-1*). The 2006 Transport for London (TFL) Bus Stop Accessibility Guideline (TFL, 2006) recommends 400m (~1310 feet) as a good approximate stop spacing distance. The Curitiba bus system (Curitiba, 2003) uses a longer stop spacing distance of 500 m (~1640 feet). Curitiba cites the stop distance as the limiting factor for the speed of buses, as major bus routes operate in exclusive rights-of-way. Table 2-3 shows a brief comparison of selected international standards.

Table 2-3: International Stop Spacing Examples

Location	Distance Between Stops (feet)	Stops per Mile
European Average <sup>1</sup>	1320 – 1760	3 to 4
London, UK <sup>2</sup>	1310 (400m)	4
Curitiba, Brazil <sup>3</sup>	1640 (500m)	3

Sources: <sup>1</sup>Furth and Rahbee, 2000; <sup>2</sup>TFL, 2006; <sup>3</sup>Curitiba, 2003

The difference between these guidelines and those by US agencies is clear. Although the foreign cities do not recommend a minimum or maximum, the average stop spacing is in most cases higher than the maximum recommended stop spacing in many US cities. European transit systems have higher market shares, and many elderly or disabled persons are able to use the routes. One reason could be the relatively high cost of gas in most European countries compared to the US, however, different transit systems have developed as well. The reason behind the development of different systems in Europe and the US is political, according to Furth and Rahbee (2000). Services in the US have fewer guidelines for stop spacing, and in some cases, any stop requests were fulfilled without further consideration. There are political benefits to placing a bus stop in a neighborhood because it is a direct, local, and visible action. However, the overall impact of placing stops wherever they are requested is a decrease of bus speeds across the course of the route (Furth and Rahbee, 2000). This is a large subject of debate but means nevertheless that we cannot assume that American stop spacing standard (or lack thereof) is best able to serve customers.

Many documents (e.g. TriMet, 2002) specify that  $\frac{1}{4}$  mile is the acceptable distance that a person should have to walk to a bus stop. During off peak or night services,  $\frac{1}{2}$  mile to 1 mile (Chicago Transit Authority [CTA], 2001) are considered optimal distances. Information supporting pedestrian access (Pedestrian and Bicycle Information Center, 2009) also states that  $\frac{1}{4}$  to  $\frac{1}{2}$  mile is the distance people will walk to access transit.

## **2.5 Site-Specific Issues**

This study focuses on the general demarcation of stop locations and the distance separation between them. Other studies have dealt with site-specific considerations with treatment options under certain scenarios. Issues to be considered relate to operations, pedestrians and others. For instance, TCRP Report 19 (1996) identifies several operations-focused factors for consideration in site-specific treatments that relate to the needs of passengers who would use the transit route, characteristics of the streets which the transit route traverses and the existence or potential for bus priority treatment. Table 2-4 summarizes the criteria for site-specific stop placement.



Table 2-4: Site-Specific Stop Placement Criteria

<b>Stop Placement Criteria</b>	<b>Explanation</b>
Adjacent land use and activities	Densely populated areas or commercial node
Bus routing	Example: Consider if bus is turning at intersection
Bus signal priority	Extended green suggests far side placement
Impact on intersection operations	Is there heavy traffic in one direction which stop will impact
Intersecting transit routes	Encourage transfer points
Intersection geometry	Wider or narrower street or lanes can create bus priority
Parking restrictions and requirements	Bus zones may remove parking
Passenger origins and destinations	Why are passengers using the route?
Pedestrian access	Accessibility for handicap/wheelchair patrons
Physical roadside constraints	Trees, poles, driveways, etc.
Potential patronage	Locations of significant passenger densities or traffic
Presence of bus bypass lane	Routes should take advantage of existing infrastructure
Traffic control devices	Bus stops placed nearside at Stops and farside at Signals

Source: TCRP Report 19 (1996), p 20

Similarly, the Transport for London Report (2006) emphasizes accessibility and appropriateness of the site for pedestrians. The report identified such pedestrian-focused criteria for site-specific considerations as:

- a. Clear visibility between driver and prospective passengers
- b. Adequate footway (sidewalk or path) width
- c. Freedom from obstructions
- d. Proximity to pedestrian crossings
- e. Availability of space for a bus shelter
- f. Minimum walking distance to transfers
- g. Proximity to intersection without affecting pedestrian safety at the intersection

TCRP Report 19 (1996) further discusses issues associated with locating transit stops close to or farther from intersections. Table 2-5 summarizes the advantages and disadvantages associated with near-side, far-side and mid-block stop locations. The terms far-side and near-side refer to the placement of stop locations at intersections. As a bus approaches an intersection, a stop located before passing through the intersection is a near-side stop; a stop located immediately after the bus passes through the intersection is a far-side stop. Any stop in between these areas is considered a mid-block stop.

Table 2-5: The Pros and Cons of Far-side, Near-Side and Mid-Block Stops

	Advantages	Disadvantages
Far-Side Stop	<ul style="list-style-type: none"> <li>• Minimizes conflicts between right turning vehicles and buses</li> <li>• Provides additional right turn capacity by making curb lane available for traffic</li> <li>• Minimizes sight distance problems on approaches to intersection</li> <li>• Encourages pedestrians to cross behind the bus</li> <li>• Creates shorter deceleration distances for buses since the bus can use the intersection to decelerate</li> <li>• Results in bus drivers being able to take advantage of the gaps in traffic flow that are created at signalized intersections</li> </ul>	<ul style="list-style-type: none"> <li>• May result in the intersections being blocked during peak periods by stopping buses</li> <li>• May obscure sight distance for crossing vehicles</li> <li>• May increase sight distance problems for crossing pedestrians</li> <li>• Can cause a bus to stop far side after stopping for a red light, which interferes with both bus operations and all other traffic</li> <li>• May increase number of rear-end accidents since drivers do not expect buses to stop again after stopping at a red light</li> <li>• Could result in traffic queued into intersection when a bus is stopped in travel lane</li> </ul>
Near-Side Stop	<ul style="list-style-type: none"> <li>• Minimizes interferences when traffic is heavy on the far side of the intersection</li> <li>• Allows passengers to access buses closest to crosswalk</li> <li>• Results in the width of the intersection being available for the driver to pull away from curb</li> <li>• Eliminates the potential of double stopping</li> <li>• Allows passengers to board and alight while the bus is stopped at a red light</li> <li>• Provides driver with the opportunity to look for oncoming traffic, including other buses with potential passengers</li> </ul>	<ul style="list-style-type: none"> <li>• Increases conflicts with right-turning vehicles</li> <li>• May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians</li> <li>• May cause sight distance to be obscured for cross vehicles stopped to the right of the bus</li> <li>• May block the through lane during peak period with queuing buses</li> <li>• Increases sight distance problems for crossing pedestrians.</li> </ul>
Mid-block Stop	<ul style="list-style-type: none"> <li>• Minimizes sight distance problems for vehicles and pedestrians</li> <li>• May result in passenger waiting areas experiencing less pedestrian congestion</li> </ul>	<ul style="list-style-type: none"> <li>• Requires additional distance for no-parking restrictions</li> <li>• Encourages patrons to cross street at midblock (jaywalking)</li> <li>• Increases walking distance for patrons crossing at intersections</li> </ul>

Source: TCRP Report 19 (1996) p 20

## **2.6 The Use of GIS in Transit Planning**

The literature acknowledges increasing use of geographic information systems (GIS) in transit planning. Horner and Murray (2004) conducted an extensive review of research on GIS use in transit planning. The study focused on the use of GIS to delineate geographical areas of demand for public transit. The authors noted the emphasis of research on modeling transit use with GIS at the expense of paying attention to spatial considerations that underlay the GIS-based analysis. The study investigated issues of spatial scale, that is, choice of individual stops vs. entire routes or Euclidean distances vs. network distances in estimating demand. The study concluded that spatial representation critically impacted the results of the analysis.

Gutierrez and Garcia-Palomares (2008) acknowledged the importance of proximity of population and employment to stops and stations on potential usage of public transit. The study focused on the choice between Euclidean vs. network distances in the creation of coverage areas, represented as buffers, with the aid of GIS. The study concluded that the method of using network-based distance provided better estimates of transit ridership than the method of Euclidean distance.

The availability of census population and employment data at the block level facilitates spatial analysis with GIS at a detailed geographic scale rather than the macro level of the traditional travel analysis zones. Previous studies confirmed that estimates of public transit coverage based on census blocks are not only the most disaggregate, but also most closely represented the population served (Horner and Murray, 2004; Peng and Ducker, 1995). That is the method employed in this study. A feature that differentiates this study from others is that the procedure includes consideration for multiple criteria, such as access to services, transfer points and grades instead of a strict focus on distance and network representation or strict employment and population coverage. Finally, consistent with other research findings, the procedure of this study used network distances to demarcate coverage areas. Unlike many other studies directed at projecting transit ridership or site treatment for stop locations this study focused on the spacing of stops under consideration of multiple factors.

## **2.7 Discussion of Literature**

Neither individual research results nor adopted guidelines of various operators seem to provide consistent indications on what should be the standards for spacing stops. The fact is there are many factors, which relate to acceptability of time to access public transit, the level of

tolerance for total travel time, the cost of providing service, the density of development and the level of patronage for transit service. Certain generalizations are in order as follows:

- a. There is general recognition that people are willing to walk  $\frac{1}{4}$ -mile to access human activities, but some people accept  $\frac{1}{2}$ -mile and under special circumstances, people would even walk a mile. Walking distance is a primary determinant of the radius that defines the catchment area of a stop. If two adjacent stops have  $\frac{1}{4}$ -mile catchment areas, then the separation between them is two adjacent radii or  $\frac{1}{2}$ -mile (2640 feet). This distance defines the upper limit of separation in adopted guidelines of operators for suburban environments. A half-mile separation is thus used in this study as the target distance for small urban and suburban areas.
- b. There is the general tendency for most study results to prescribe shorter distances for dense urban areas than for more sparsely developed areas. This is reflected in the adopted guidelines of operators although the actual distance of separation is widely variable. Simulation results and guidelines from abroad all seem to point to approximately four stops per mile or  $\frac{1}{4}$ -mile separation (1320 feet) which would result in a non-overlapped catchment area radius of  $\frac{1}{8}$ -mile per station. A quarter-mile separation is thus used in this study as the target distance for large urbanized areas.
- c. There are two variations from these two target distances. One relates to separation for “express” or “rapid” service, which tends to be two times the prevailing separation or  $\frac{1}{2}$ -mile to a mile. The other relates to steep segments of 10 percent grade or more, which tend to prescribe half the prevailing separation.

## **3.0 Case Study Locations**

### **3.1 Introduction**

The study collected transit route system data from transit operators in two case study locations. One case study is the City of San Francisco to be representative of a central city type of environment. It also provides variations in topographical characteristics. Transit system information and data were procured from the San Francisco Municipal Transportation Agency (SFMTA). The second case study is San Luis Obispo County to be representative of a suburban type and a small urban type of environment. The county provides wide variations in the density of people and proximity to stop locations. Transit system information and data were procured from the San Luis Obispo Council of Governments (SLOCOG) for two transit operations: (a) San Luis Obispo Transit (SLO Transit) and (b) the Regional Transit Authority (RTA).

Data collected for the case study routes included the following:

- a. Route network to identify general alignments of major intra-area and cross-area routes as well as key transfer points;
- b. Route profile data to identify high ridership points;
- c. Field inventory of stop locations to identify availability of amenities such as shelters, seats, rider information, etc.; and
- d. Major activity locations, that is, key origins and destinations such as major markets, employment centers, and recreational spots and so on.

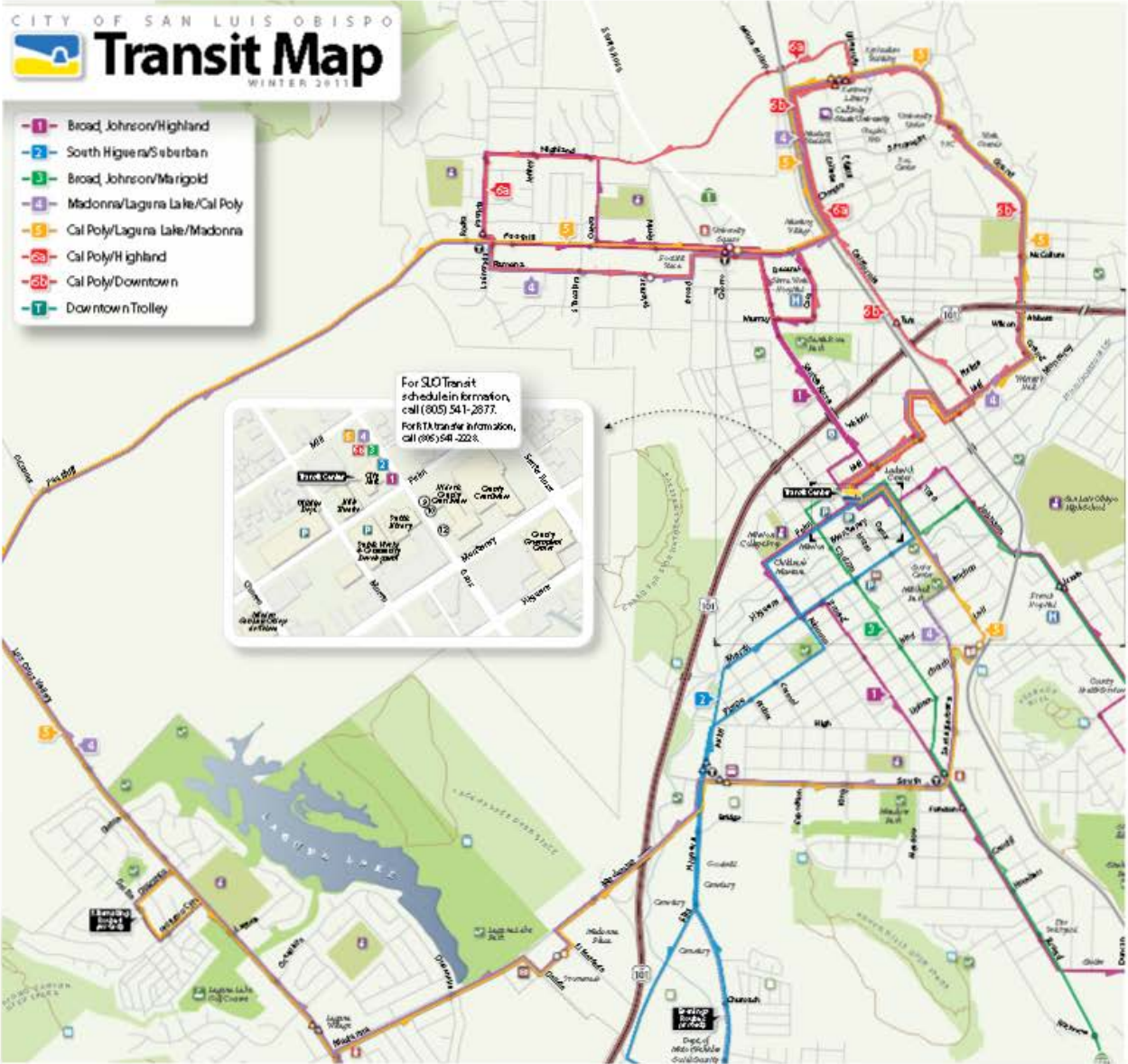
All case study information was stored in a Geographic Information System (GIS). Other important information to help the analysis included point and shapefiles for case study locations on transit routes, road systems, topography and major activity centers.

### **3.2 Small Urban Case Study Location**

The small urban case study site is the City of San Luis Obispo located in Central San Luis Obispo County half way between the large metropolitan areas of San Francisco in the north and Los Angeles in the south. The City was selected because of its relative small size with 2010 population of 45,119 people (U.S. Census, 2010) and its proximity to the study investigators. The transit operator is San Luis Obispo Transit. Route 4 was selected for the case application because it loops across the City, reaching several population and activity centers as shown in Figure 3-1, a partial transit route map of the City.

Figure 3-1: Partial Route Map of San Luis Obispo Transit, California

Source: [www.slocity.org/publicworks/download/busmap.pdf](http://www.slocity.org/publicworks/download/busmap.pdf)



### **3.3 Suburban/Rural Case Study Location**

The suburban/rural case study site is also within San Luis Obispo County. The County was selected because of its proximity to investigators and its relatively sparse 2010 population of 269,637 people (U.S. Census, 2010) spread across a dozen cities. The transit operator for cross-county travel is the Regional Transit Authority. RTA route 9 and route 10 were selected for study because together they traverse the County from north to south via the City of San Luis Obispo as shown in Figure 3-2.

### **3.4 Large Urban Case Study Location**

The large urban case study site is the City of San Francisco located in northern California. The City was selected because of its relative compact build, its reputation as a transit-friendly city with several different public transportation modes, routes and services for its 2010 population of 805,235 people (U.S. Census, 2010). The transit operator is San Francisco Municipal Transportation Agency. Route 2 runs east-west through the northern portion of the City, connecting with downtown. Route 49 runs north-south across the City. Route 71 also runs northeast-southwest through the central section of the City. These routes were selected for the case application because together they cut across different corridors of the City, reaching several population and activity centers as shown in Figure 3-3, a partial public transit route map of the City.

**Figure 3-2: Route Map of San Luis Obispo County Regional Transit Authority**

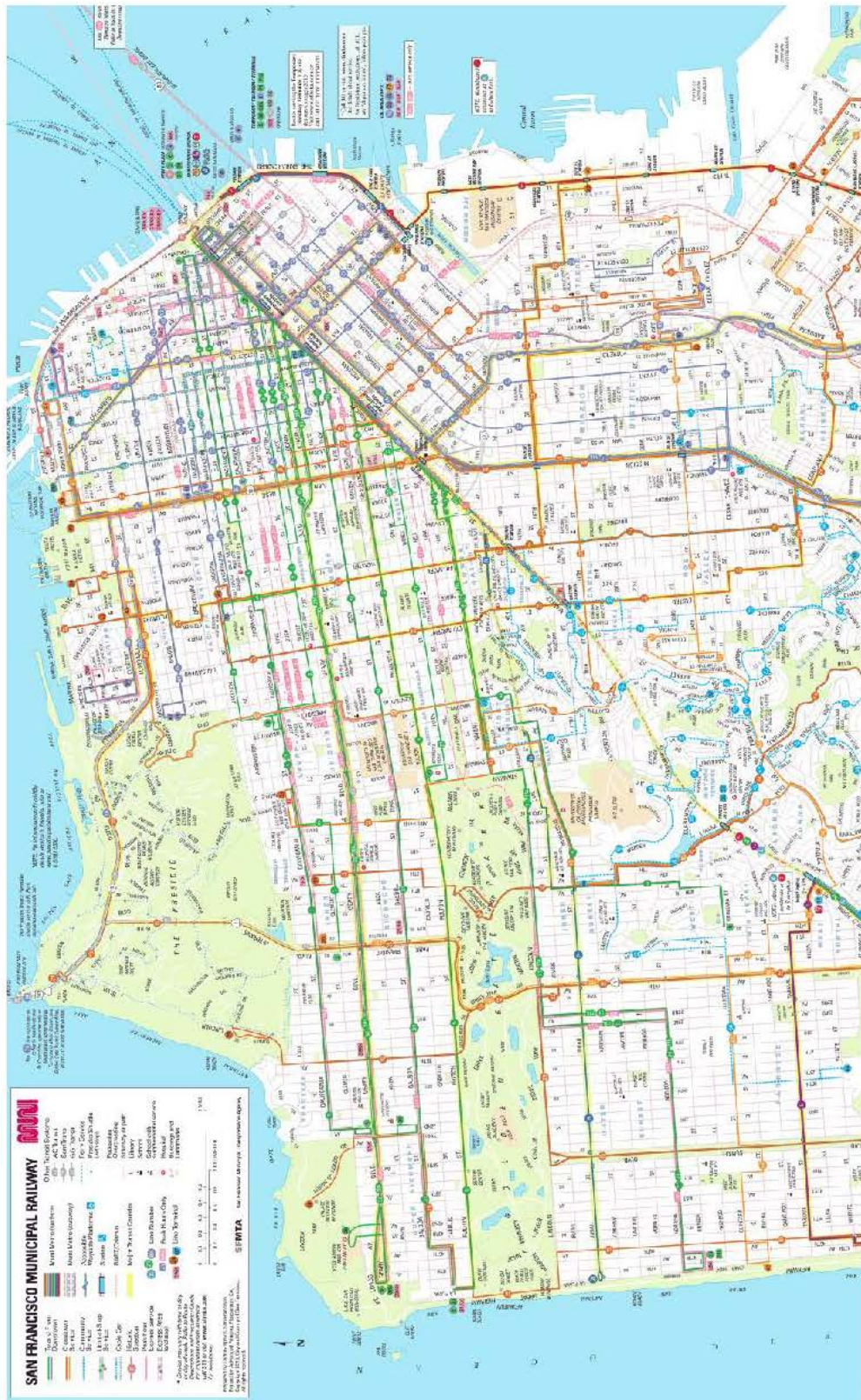
Source: <http://www.slorta.org/images/stories/Schedules/rta9.pdf>





**Figure 3-3: Partial Route Map of San Francisco, California**

Source: [http://transit.511.org/static/providers/maps/SF\\_1222201020400.gif](http://transit.511.org/static/providers/maps/SF_1222201020400.gif)



## **4.0 The Process of Selecting Stop Locations**

### **4.1 Key Factors**

A systematic process is developed for selecting stop locations. The process depends on the following key factors:

Population concentrations – are a primary factor as public transit is to serve people. It is preferable that stops are within easy access distance of the highest concentrations of people. These determine both stop locations and potential alignments of transit routes.

Employment concentrations – are similarly a primary factor in determining stop location because they tend to identify destinations of high activity, which draw high numbers of people. These determine both stop locations and potential alignments of transit routes.

Proximity to activity centers – is closely related to employment concentrations. Activity centers are destinations of common interest to many people and are best served directly by stops. These determine both stop locations and potential alignments of transit routes.

Connectivity with cross-routes for transfers – this factor enhances the accessibility of the public transit system when the stop location makes it convenient to transfer to other transit routes.

Transferability to other modes or routes of travel – this factor enhances the utility of public transit when the placement of stops enables direct connections to other modes of transportation to facilitate reaching desired destinations conveniently.

Ability of a threshold population within a catchment area to reach the stop location – is a key factor in determining the separation between stops.

Steep grade along route segments – is used to determine if special consideration should be given for shorter spacing of stops.

Public input – is important in choosing from alternative locations that are close to each other and in confirming transfer and connection points identified from data.

### **4.2 Conceptual Overview**

The bus stop spacing procedure, whether for a new or existing route, encompasses the step-by-step inclusion of the key factors. The process in a nutshell is outlined as follows:

1. Identify population concentrations by census block using Census data for the latest available year. To do this, create a Raster map (or dot thematic map) of concentrations of people in a GIS software.
2. Identify major employment concentrations by census block using the latest available employment and shapefile data from Census LEHD website. To do this, create a Raster map (or dot thematic map) of concentrations of jobs in a GIS software.
3. For an existing route, add the existing transit route configuration and stops to the map.
4. For a new route, use the thematic maps to determine the general alignment for the route to connect high intensity centers.
5. Identify cross route locations for transfers and add them to the map
6. For an existing route, add a database of amenities (shelter, benches, route maps, etc.) present at individual stop locations and add them to the map. These can help in stops to retain where choices need to be made between adjacent stops.
7. Identify primary stop locations from the previous steps.
8. Create buffers of 0.25-mile radius around the primary stops.
9. For an existing route, use the buffers to determine where there is too much overlap so as to flag potential stops for elimination or re-positioning; in other areas, use the buffers to identify intermediate locations to achieve convenient, walkable access from nearby land uses.
10. For new routes, use the buffers to determine intermediate locations to achieve convenient, walkable access from nearby land uses.

### **4.3 Illustration of Application Process**

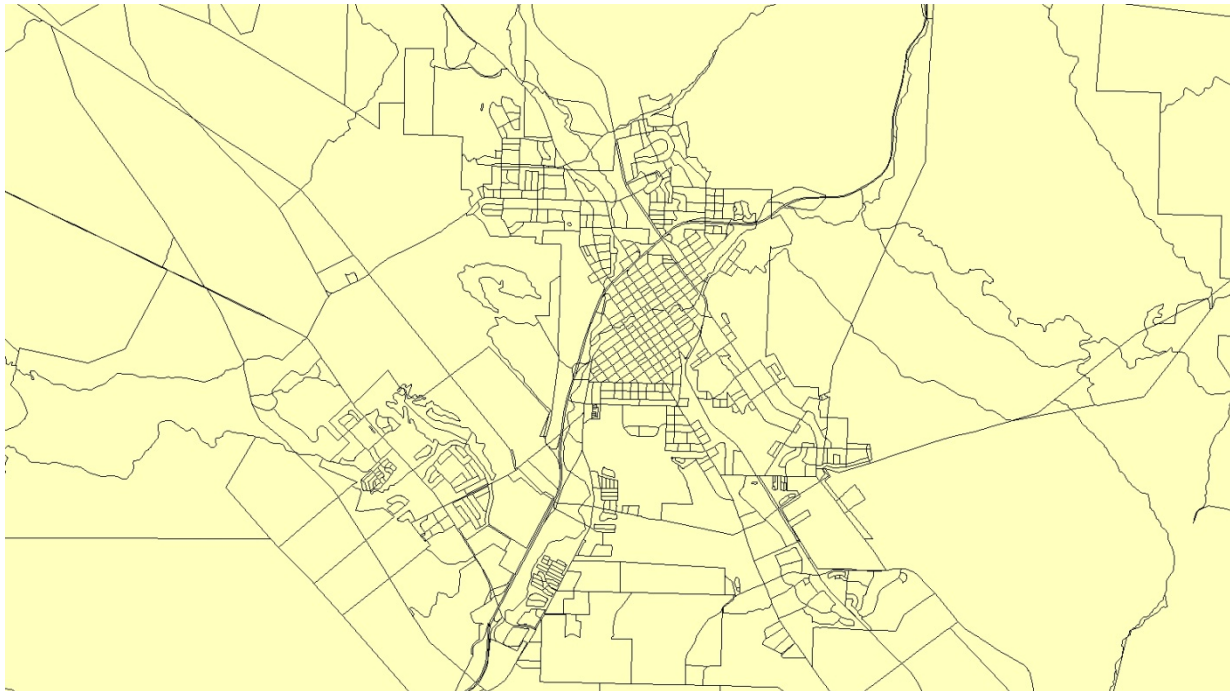
This section illustrates the process, using SLO Transit's route 4 in San Luis Obispo City. Population data and much of related shapefiles for census blocks were obtained online from the US Census Bureau. Employment data and related shapefiles were obtained from the US Census LEHD web site. Esri's ArcGIS 10 was used for mapping and database coordination.

**Step 1: Retrieve initial data**

1. 2010 block shapefiles are available from:  
<http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html>
2. 2010 Block population data is available at: <http://www.census.gov/>
3. For employment calculations, download block shapefile for the most recent available year from: <http://www.esri.com/data/download/census2000-tigerline/index.html>
4. For this sample illustration, 2010 population and 2007 employment data were used.

Figure 4-1 shows the map of the study City for this illustration.

**Figure 4-1: Map of San Luis Obispo City**



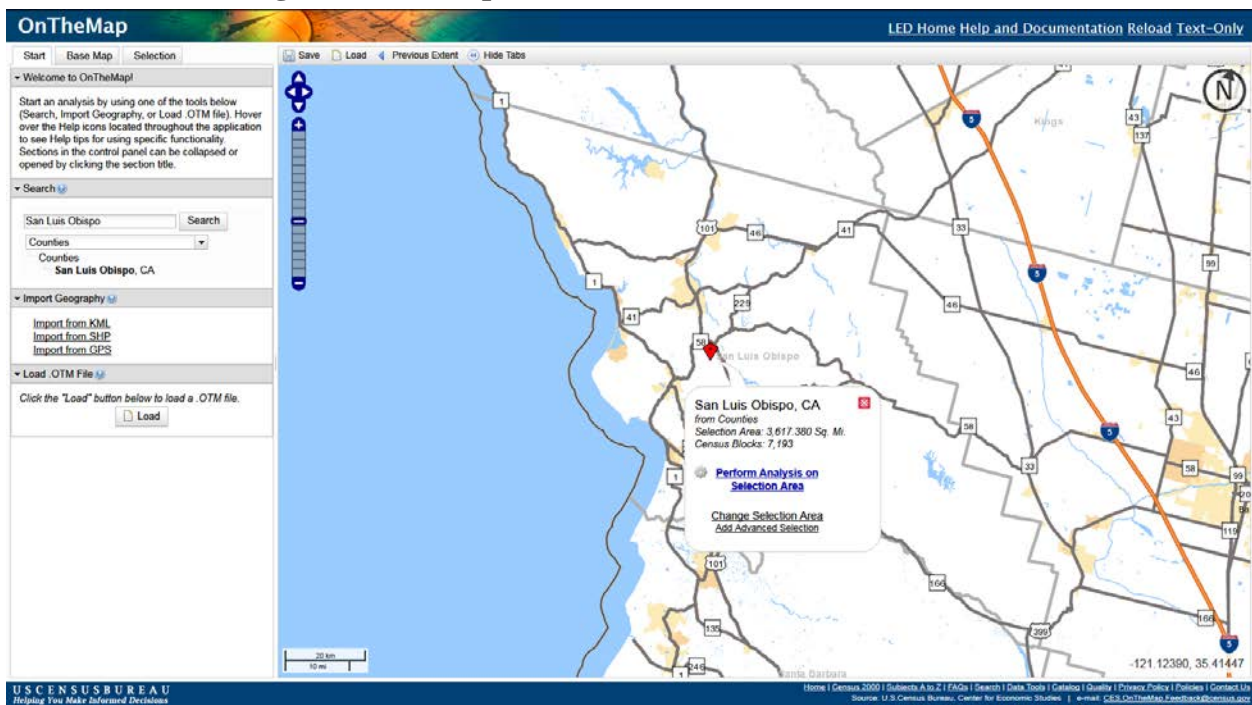
**Step 2: Retrieve employment data based on census blocks from LEHD.**

1. Go to LEHD: <http://lehd.did.census.gov/led/>
2. Select analysis area (ex. San Luis Obispo City)
3. Select 'Perform selection on Analysis Area'
4. Under Analysis Setting, select the following

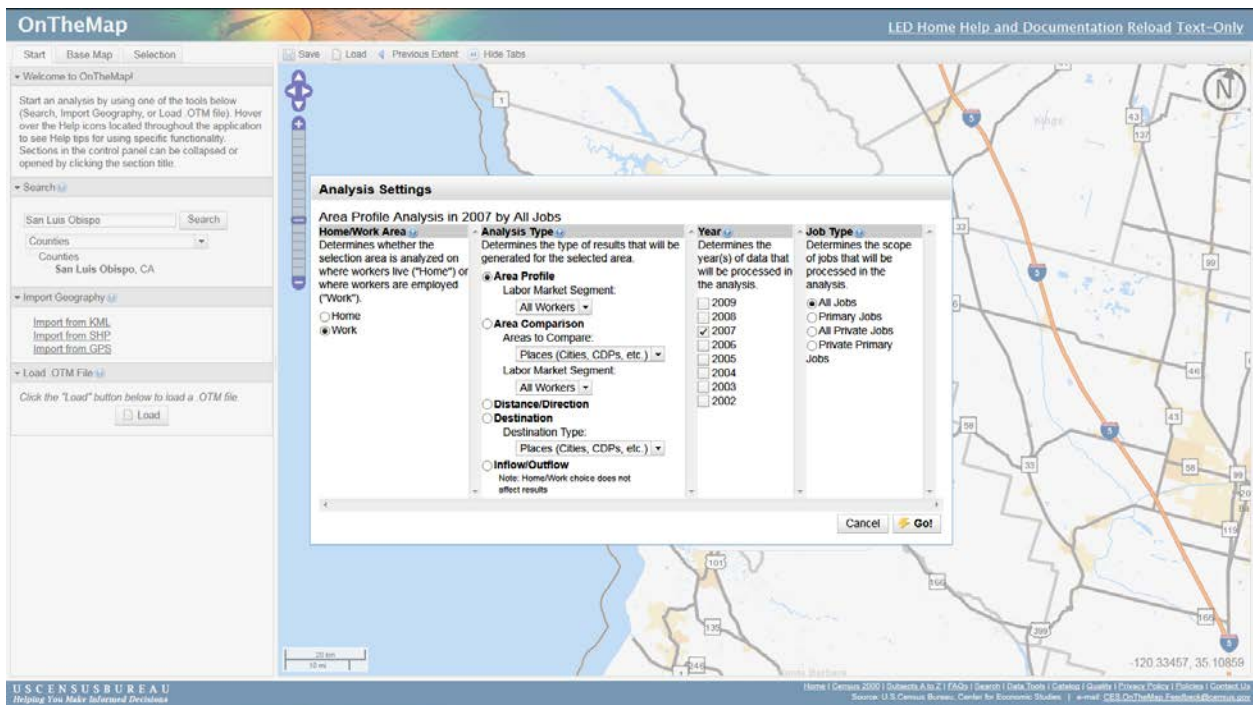
- a. Home/Work Area – Work
  - b. Analysis Type – Area Profile (All Workers)
  - c. Year – 2007 (this year was selected to enable verification against the 2007 economic census data in case there were any errors.)
  - d. Job Type – All Jobs
5. When the operation completes, select ‘Export Geography’, and select the shapefile export.

Figures 4-2 show LEHD interfaces for the place selection and request for data.

**Figure 4-2a: Sample LEHD Interface for Place Selection**



**Figure 4-2b: Sample LEHD Interface for Data Request**



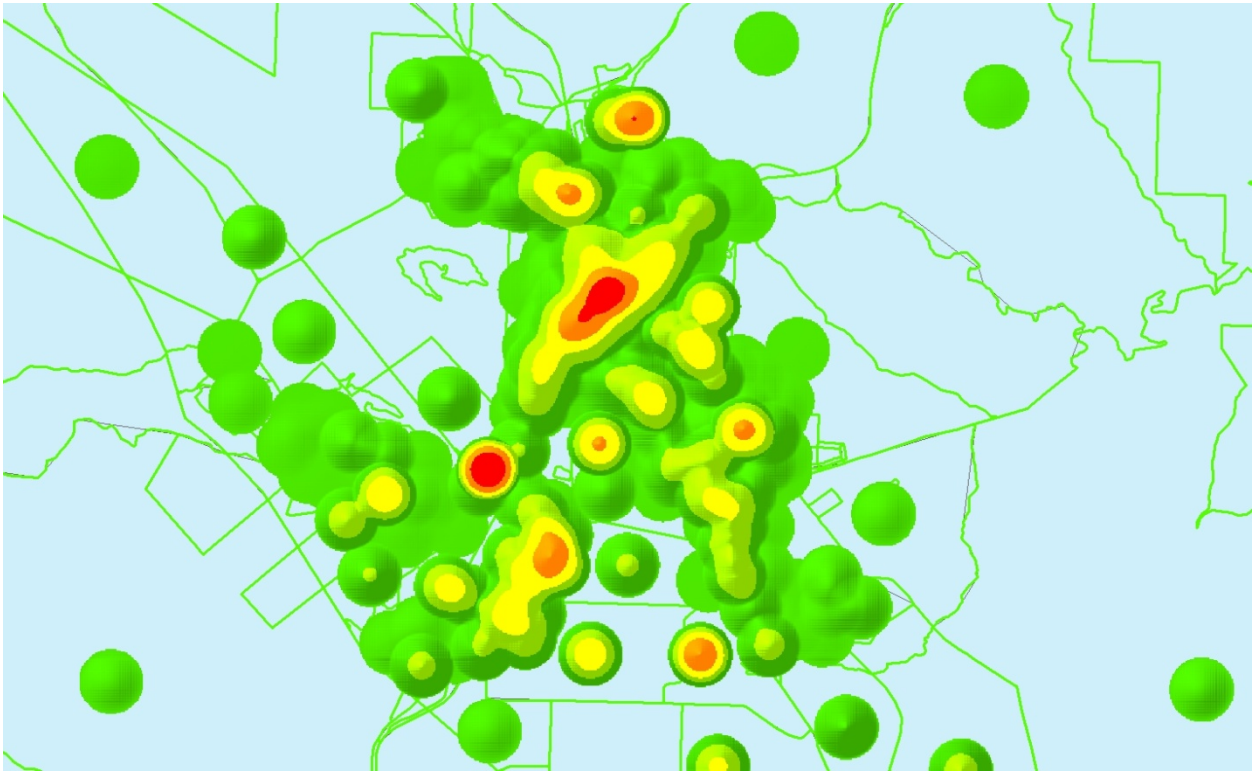
**Step 3: Create raster layers in GIS**

1. Extract the data and import the shapefile into GIS.
2. View the attribute table for the shapefile. Notice the column labeled 'c000'. This column contains the total number of jobs per census block for the analysis year. You can do a quick summary statistics on the column to verify the sum for the county. Check it against the LEHD website data. It should match the total there. You may want to rename this column something more descriptive (e.g. Jobs2007).
3. Join the jobs point shapefile to a blank census block 2000 shapefile using the census block unique identifier (long number) rather than FID. This enables the employment data to skip blocks that do not have employment numbers.
4. Create a point shapefile from the census block 2000 shapefile. This is the shapefile used to create the raster layer using the following sequence in ArcGIS:
  - a. ArcToolbox > Data Management > Features > Feature to Point
5. Check employment values and centroid locations to be sure they are a correct reflection of reality.

6. After editing, create a raster image:
  - a. ArcToolbox > Spatial Analyst > Density > Kernel Density
  - b. Input point features = The employment point shapefile
  - c. Population field = c000 (This may appear as whatever alias you gave the field if you renamed it, or the name may have changed with all the previous joining of data fields. You'll probably want to query the columns in the attribute table to identify if that's the case)
  - d. Output raster = wherever you want the output saved ... you might want to name it something like "job\_density"
  - e. Output cell size = 50; this is for fifty-foot cells.
  - f. Search radius = Input '1320' for a quarter mile search radius.
  - g. Area Units = One can select the density per square mile or per acre. This sample illustration elected to use density per acre. One can experiment between the two density units. No matter what area units are selected, the pattern of the density layer would remain similar except for greater density ranges for square miles.
7. Make optional adjustments to the layer using:
  - a. For symbology, select "classified".
  - b. Change the number of classes
  - c. Change the color ramp to colors and shades that are logical to you
  - d. Use the hillside shade effect box (3D effect)
  - e. Use Classify
  - f. Change the classification method
  - g. Use the data exclusion button

Figure 4-3 shows a sample Raster image of employment concentrations in San Luis Obispo.

**Figure 4-3: Raster Surface of Employment Density in San Luis Obispo City**



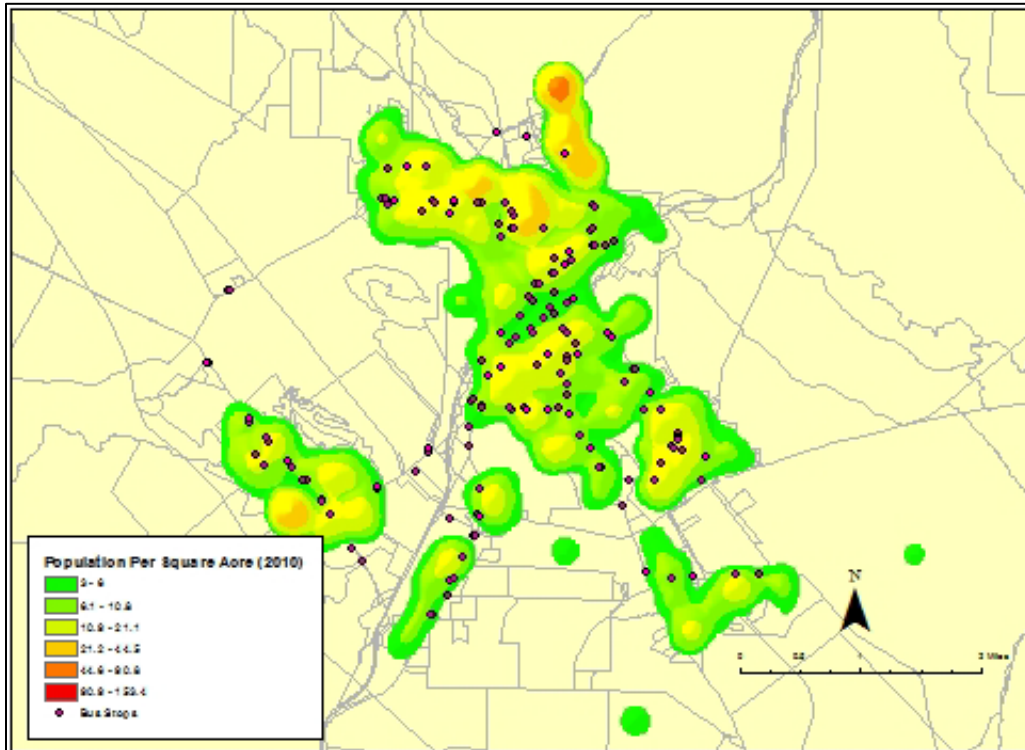
***Step 4: Finalize population and employment images***

1. Add additional shapefiles, such as transit stops or routes for comparison.
2. Add title, legend, scale, and direction

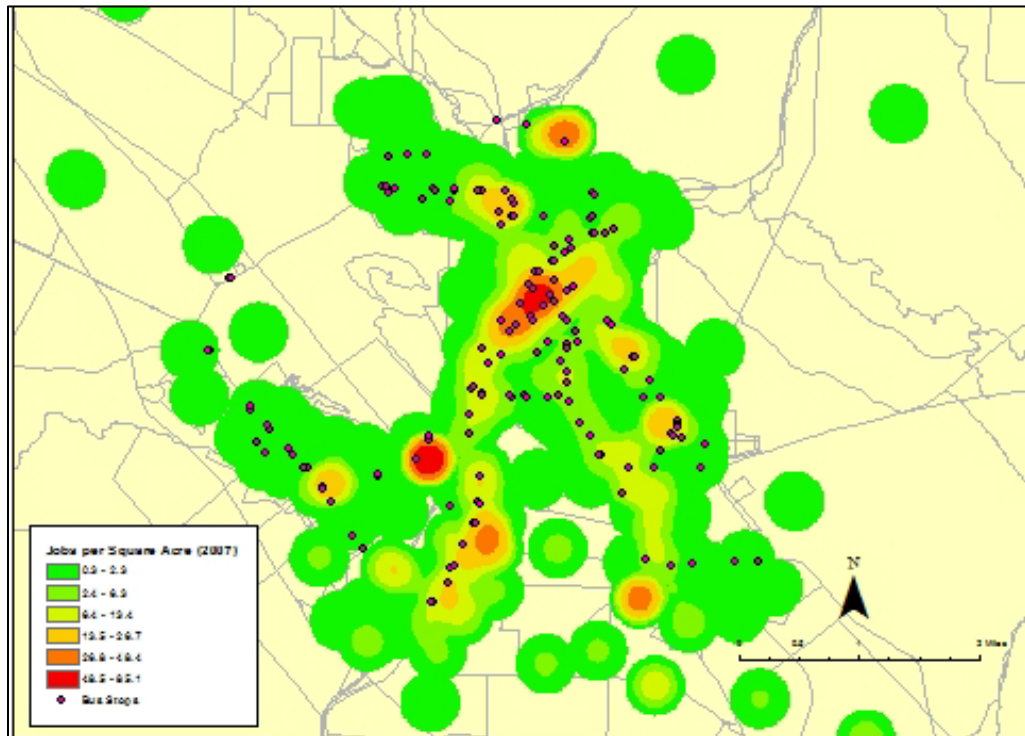
Figures 4-4 show population and employment densities for San Luis Obispo. The maps show that existing bus stops (represented by dots) track employment density very well and population density fairly well.



**Figure 4-4a: Raster Surface of Population Density in San Luis Obispo City**



**Figure 4-4b: Raster Surface of Employment Density in San Luis Obispo City**



**Step 5: Choose routes for analysis.**

1. After reviewing the goals of the project, choose routes that meet your criteria for analysis. These could include:
  - a. Whether routes pass through main employment or population centers.
  - b. Whether routes adequately cover different areas of the City (e.g. whether South to North or East to West corridors are well served)
  - c. If ridership data is available for existing stop locations, one can compare them to the main population and employment locations.

Selected routes can also be a combination of routes that pass through important nodes. In this illustrative case, the process is applied to SLO Transit route 4, which loops through the City reaching the major university campus, downtown and major shopping areas with residential concentrations in between.

**Step 6: Mark significant locations along each route.**

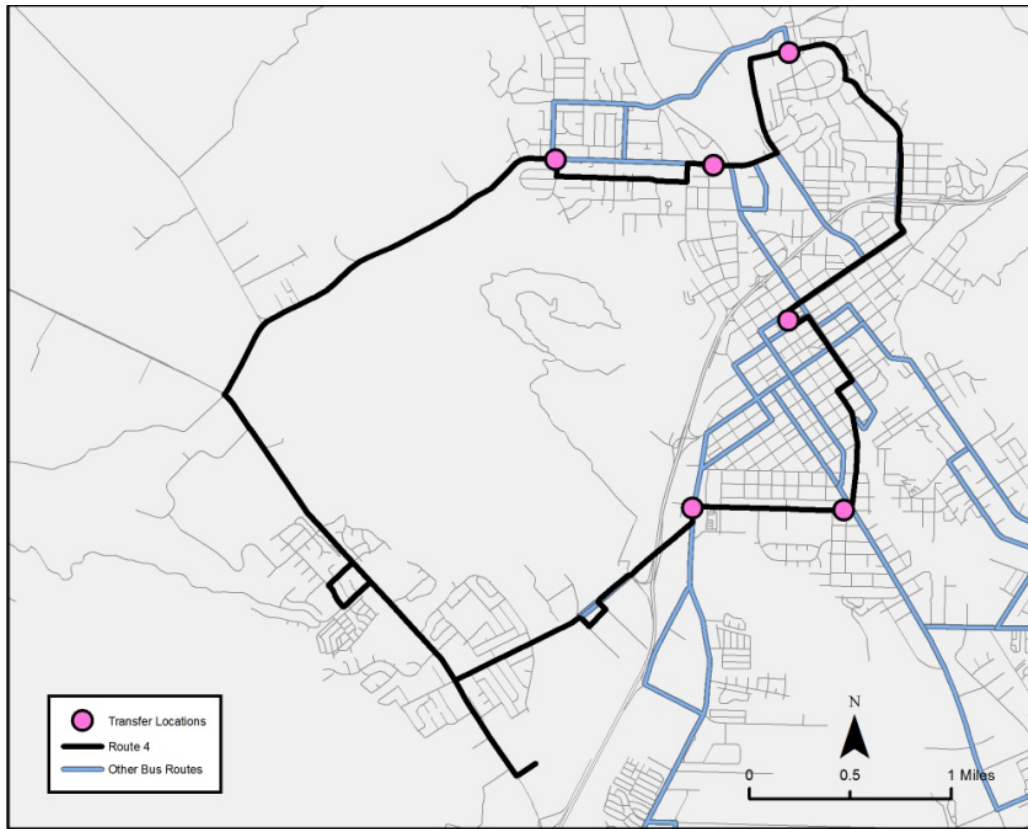
1. Significant locations are determined from a combination of the following:
  - a. Major population concentrations
  - b. Major employment concentrations
  - c. Major activity centers such as hospitals, schools, parks, etc.
2. For application to an existing route, the stop locations along the route would be displayed at this point. The analyst can begin to see the correspondence between existing stops and these major factors of stop location.

**Step 7: Mark potential transfer locations.**

1. Look at all possible locations, not just major transfer locations, in order to give the greatest flexibility of options in Step 10.
2. At this point, we use the draw point function, rather than creating a new point shapefile, as there could be numerous changes in which points are kept or removed throughout the process.

In the sample application, the transfer locations are the pink-colored points on the map. Figure 4-5 identifies these locations.

**Figure 4-5: Potential Transfer Points along SLO Transit Route 4**

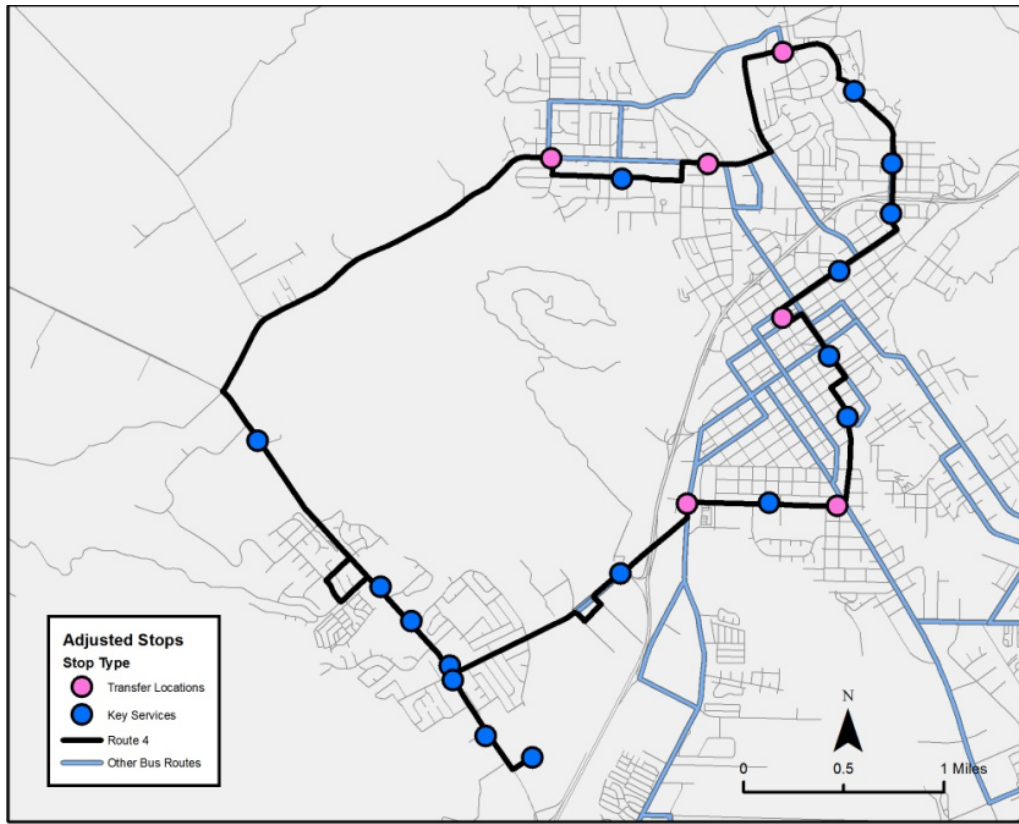


**Step 8: Mark key locations along the route.**

1. Using either existing data layers or knowledge of the community, mark key locations of services that people will need to access including:
  - a. Police stations
  - b. Post offices
  - c. Clinics
  - d. Medical centers
2. These locations should not change frequently. Routes and stops should change as infrequently as possible while remaining useful in order to provide maximum usability to the riders.

In the sample application, the transfer locations are the blue-colored points on the map. Figure 4-6 identifies these locations.

**Figure 4-6: Key Services and Facility Locations along SLO Transit Route 4**



***Step 9: Determine segments with steep slopes, which might therefore have different stop spacing requirements.***

This step assumes slope data exists for each street segment. The sample application did not have street segments with steep grades along the route’s alignment.

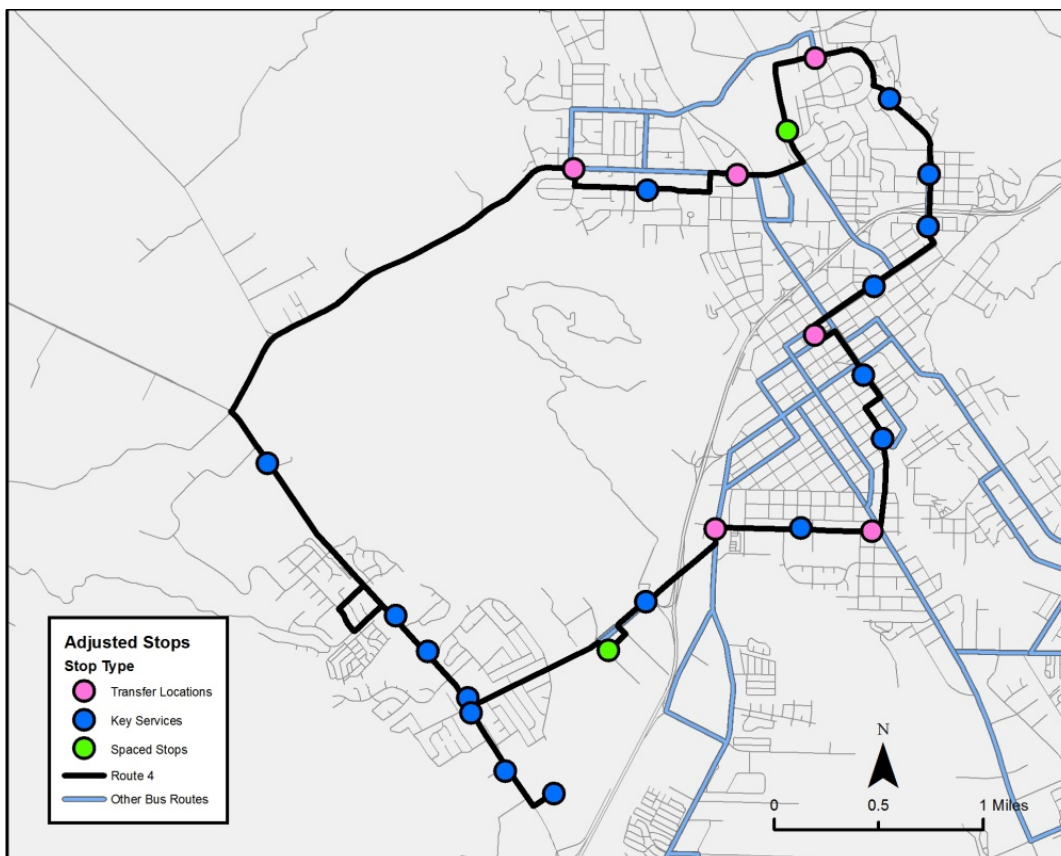
***Step 10: Place stops along the route considering all previously discussed factors.***

1. Start at one end of the route (e.g. in the inbound direction).
2. Select a target distance separation between stops.
  - a. For a  $\frac{1}{4}$ -mile walking distance, the radius of two nominal buffers back-to-back is  $\frac{1}{2}$ -mile or 2640 feet. Use this target distance for small urban, suburban and rural areas
  - b. Four stops per mile would mean  $\frac{1}{4}$ -mile or 1320 feet separation. Use this target distance for large urban areas.

- c. These target distances are tempered: to provide more direct access to major activity centers; to provide greater separation for express service routes; to improve walk access in steep grade segments.
3. Use the measuring tool to find the distance between adjacent stops.
  - a. The target distance in this illustrative case is 2640 feet or 1/2 of a mile.
  - b. For example: the distance between two stops on this case study route was roughly 1120 feet. Removing one potential stop and moving the bus stop further down the route brought the distance between the two stops close to 2640 feet.
4. Continue in the same manner, checking the population and employment layers and aiming to place stops in areas with the highest population or employment densities.

In the sample application, the additional locations are the green-colored points on the map. Figure 4-7 identifies these locations.

**Figure 4-7: Complete Placement of Stops along SLO Transit Route 4**



### 4.4 Validation of Application Process

This section compares stop locations with population and employment concentrations, and accessibility. It also checks for the degree of overlaps in the placement of stops. The optimal placement of stops would prioritize access to the highest concentrations of people and activities and minimize overlaps in the catchment areas of stops. Figure 4-8 compares the placement of stops with population concentrations. With minimal re-location of a few stops, the final results show that the existing route alignment and stop locations match up with the population centers very well. Similarly, Figure 4-9 shows a very good match between stops and job centers. Figure 4-10 provides an even more definitive validation of route alignment and stop locations with a combined map of population and employment concentrations.

The following sections of the report present analyses of the application process as applied to different transit routes that are in existence in small urban, suburban/rural and large urban environments. These analyses provide additional validation of the application process.

**Figure 4-8: Stop Placement vs. Population Density along SLO Transit Route 4**

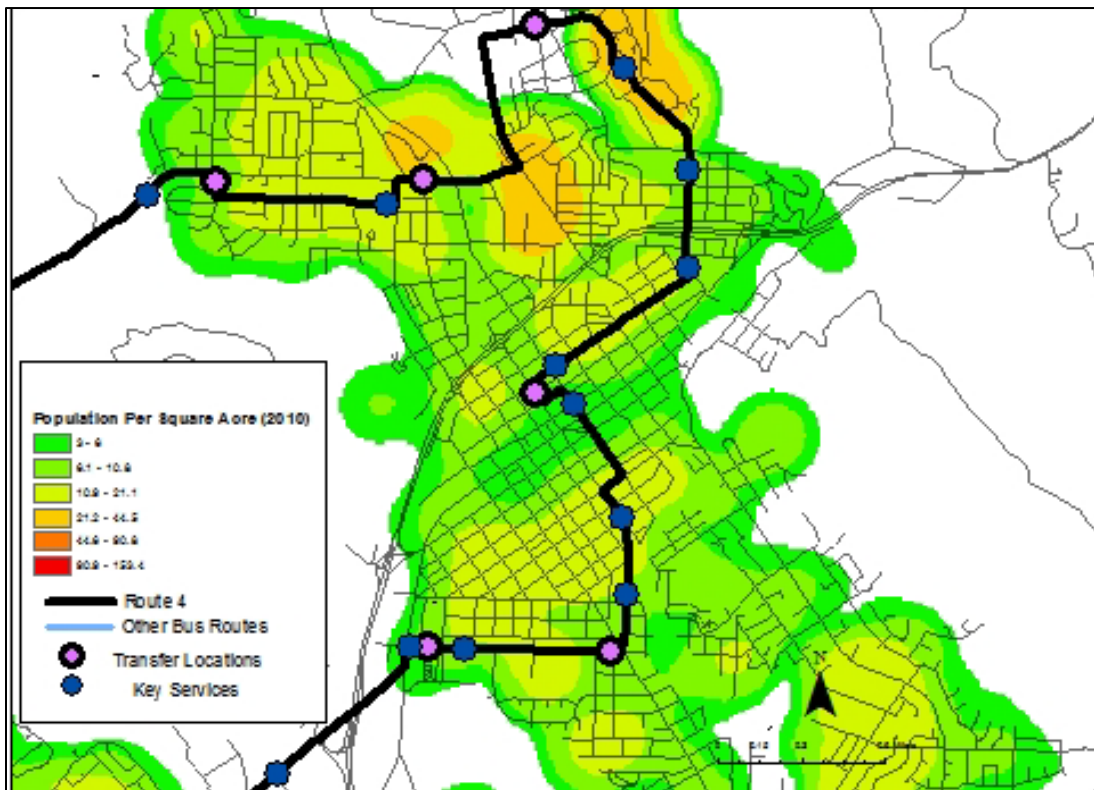


Figure 4-9: Stop Placement vs. Employment Density along SLO Transit Route 4

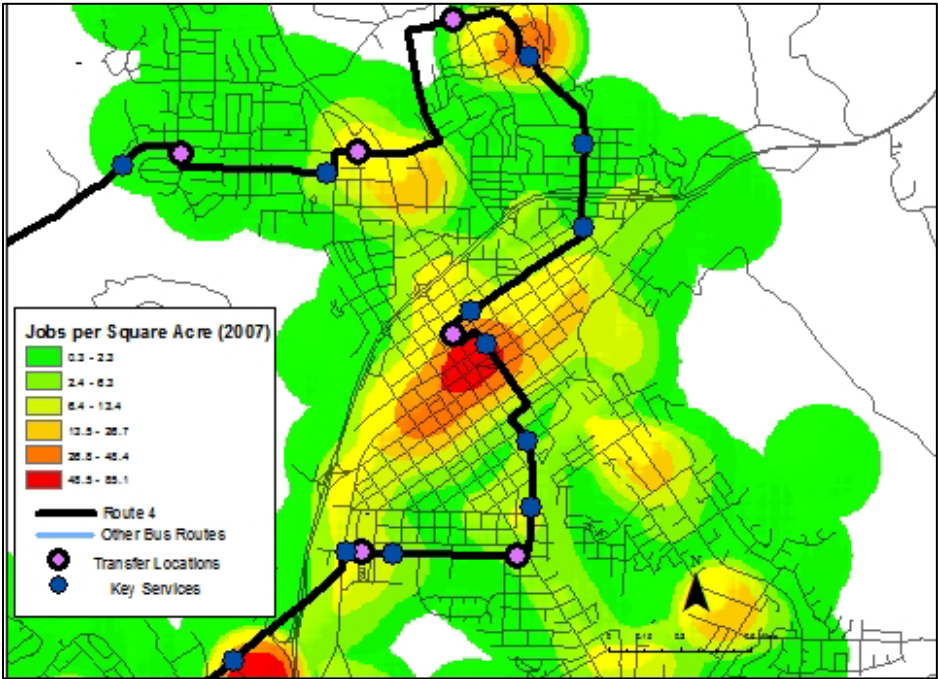
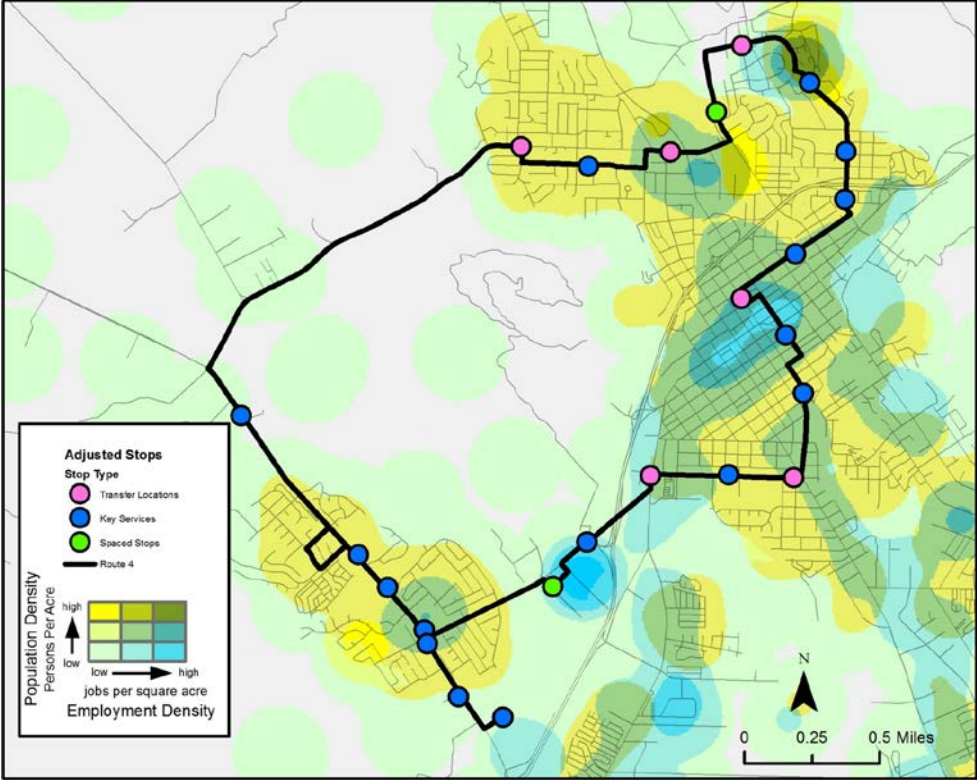


Figure 4-10: Route Alignment and Stops vs. Activity Concentrations along Route 4



## 5.0 Application: Small Urban Area Route in San Luis Obispo

### 5.1 Application Process for SLO Transit Route 4

#### 5.1.1 Early Steps

The early steps of the application process for SLO Transit Route 4 were presented in the illustrative case in Section 4. This section focuses on analysis of the match and the accessibility between activity concentrations and stop locations of this case study route.

#### 5.1.2 Other Key Stop Placement Steps

The other key stop placement steps of the application process for SLO Transit Route 4 were presented in the illustrative case in Section 4. These included marking locations for: (a) transfer opportunities (in pink dots); (b) service and activity centers (in blue dots); (c) target distance separation of 0.5 mile for a walk access of 0.25 mile to nearest stop (in green dots). Then superfluous stops were removed or re-positioned to eliminate excessive overlapping of 0.25-mile buffers around stops while taking into account the population and employment densities. Associated maps were shown as Figures 4-5 to 4-10.

### 5.2 Analysis of Accessibility to SLO Transit Route 4

SLO Transit Route 4 had 34 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.25-mile buffer distances (0.5-mile diameter), is 4.29 square miles of which 1.95 square miles of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 45 percent overlap in catchment areas of stop locations. Figure 5-1 shows buffer overlaps under existing conditions.

Applying the procedure of this study would result in 19 stop locations with a total coverage area of 3.75 square miles. Of that coverage area, 0.89 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 23 percent or approximately half of the existing condition. Figure 5-2 shows buffer overlaps under adjusted conditions.

Figures 5-3 and 5-4 present zoomed-in views of sections of SLO Transit Route 4 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 5-5 and 5-6 show the same comparative overlap information superimposed over a base map of activity concentrations.



Figure 5-1: Buffer Overlaps along Route 4 under Existing Conditions

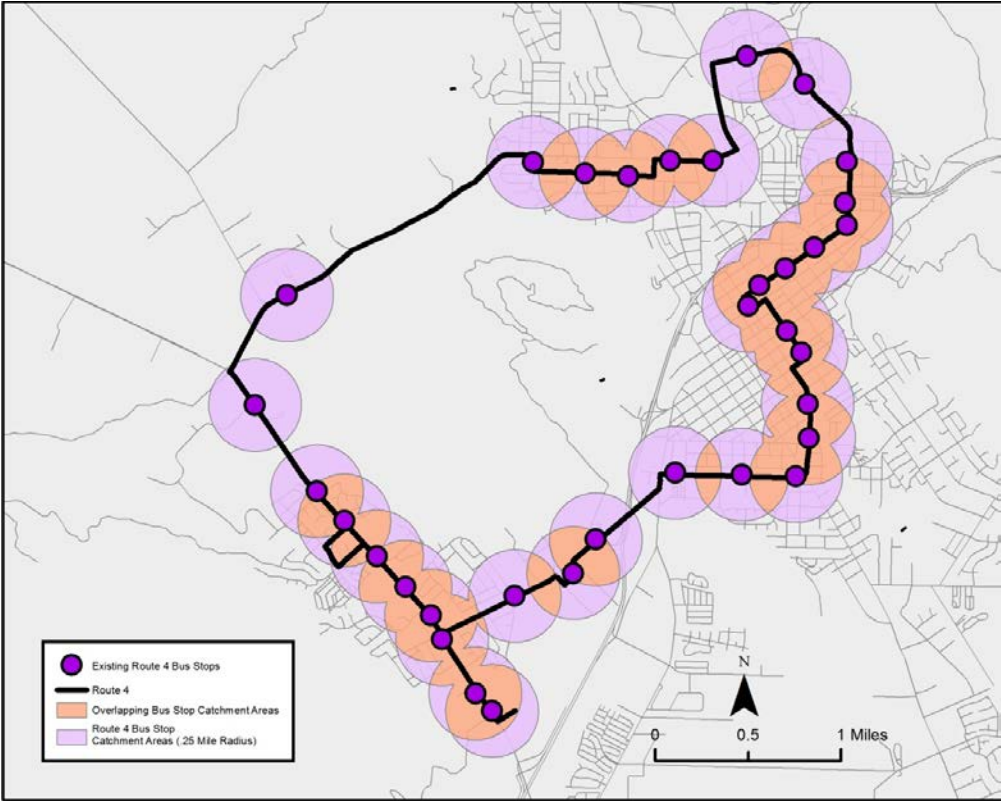


Figure 5-2: Buffer Overlaps along Route 4 under Adjusted Conditions

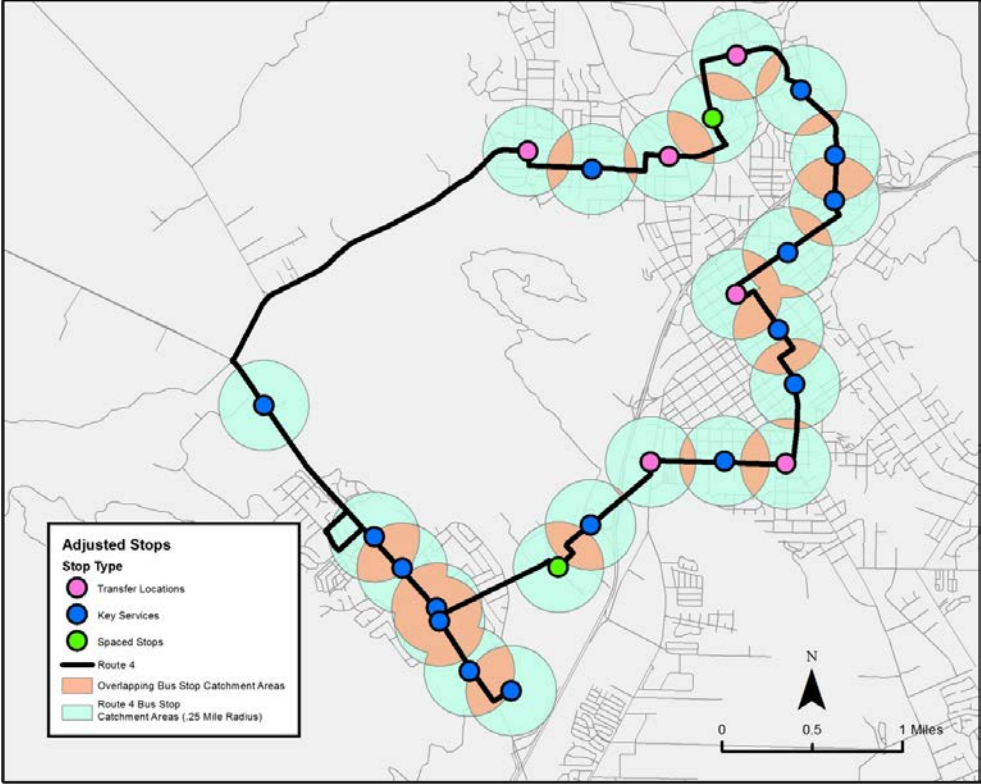


Figure 5-3: Comparative Buffer Overlaps along Route 4 (1 of 2)

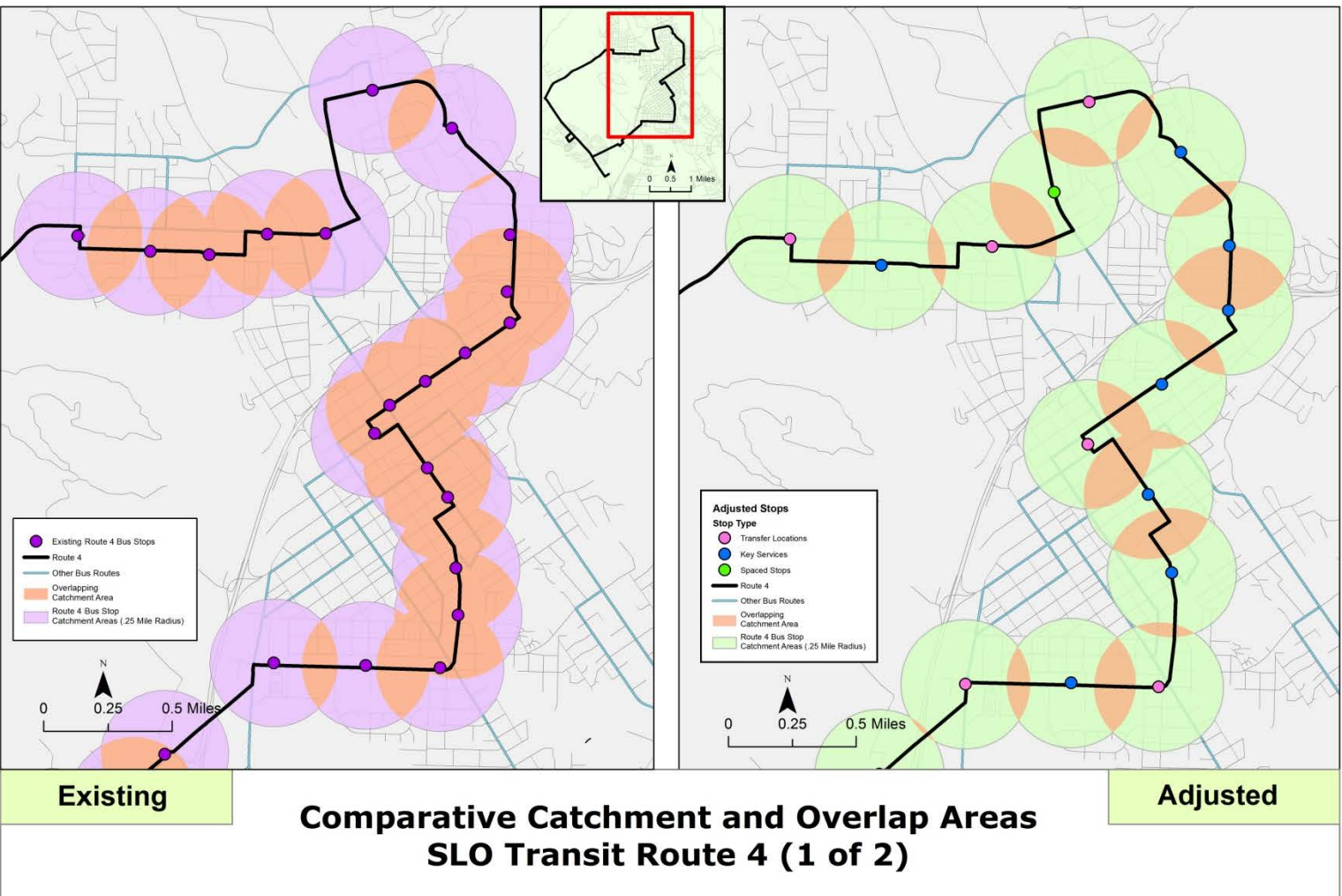


Figure 5-4: Comparative Buffer Overlaps along Route 4 (2 of 2)

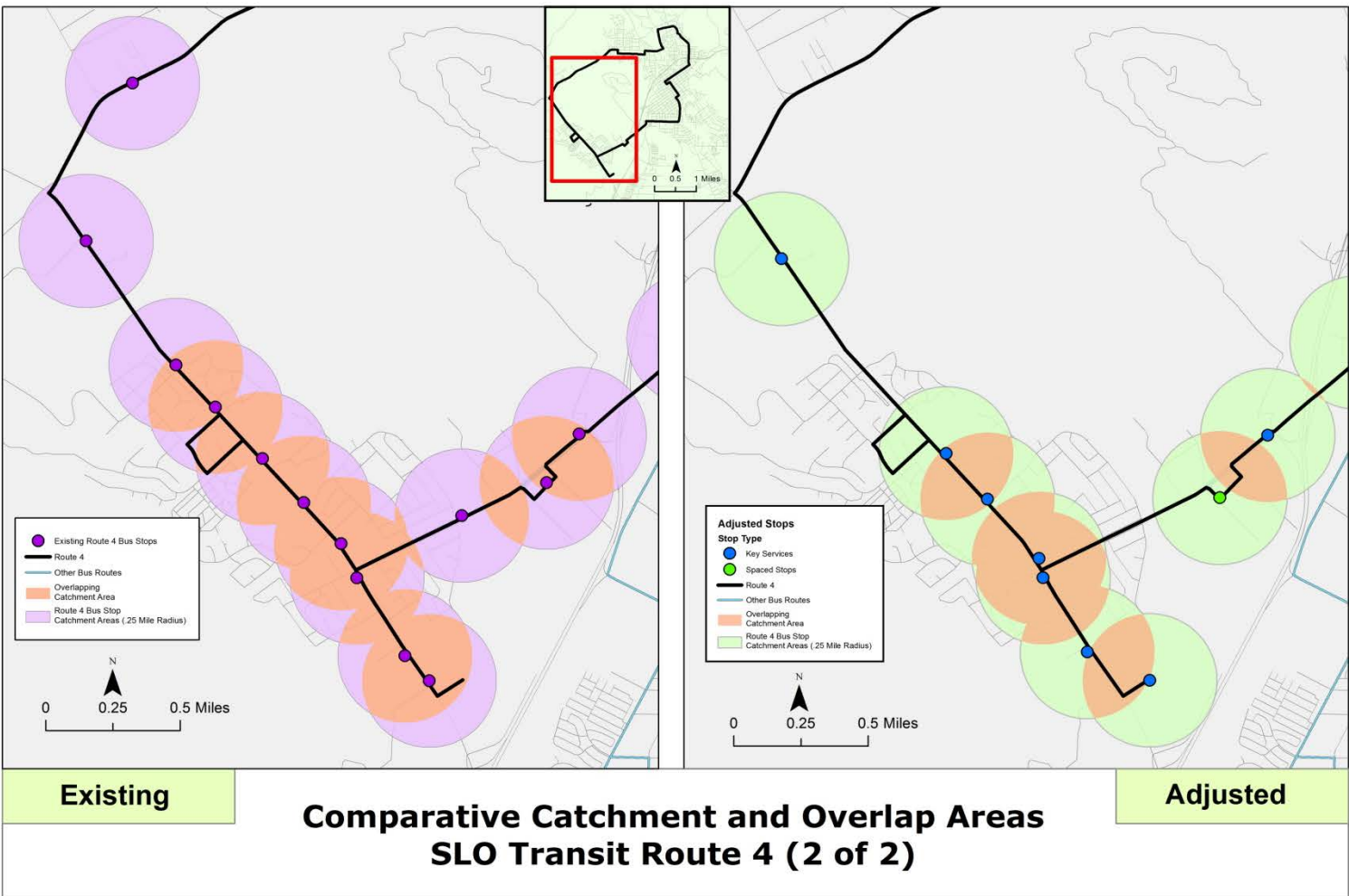


Figure 5-5: Comparative Buffer Overlaps vs. Activity Centers along Route 4 (1 of 2)

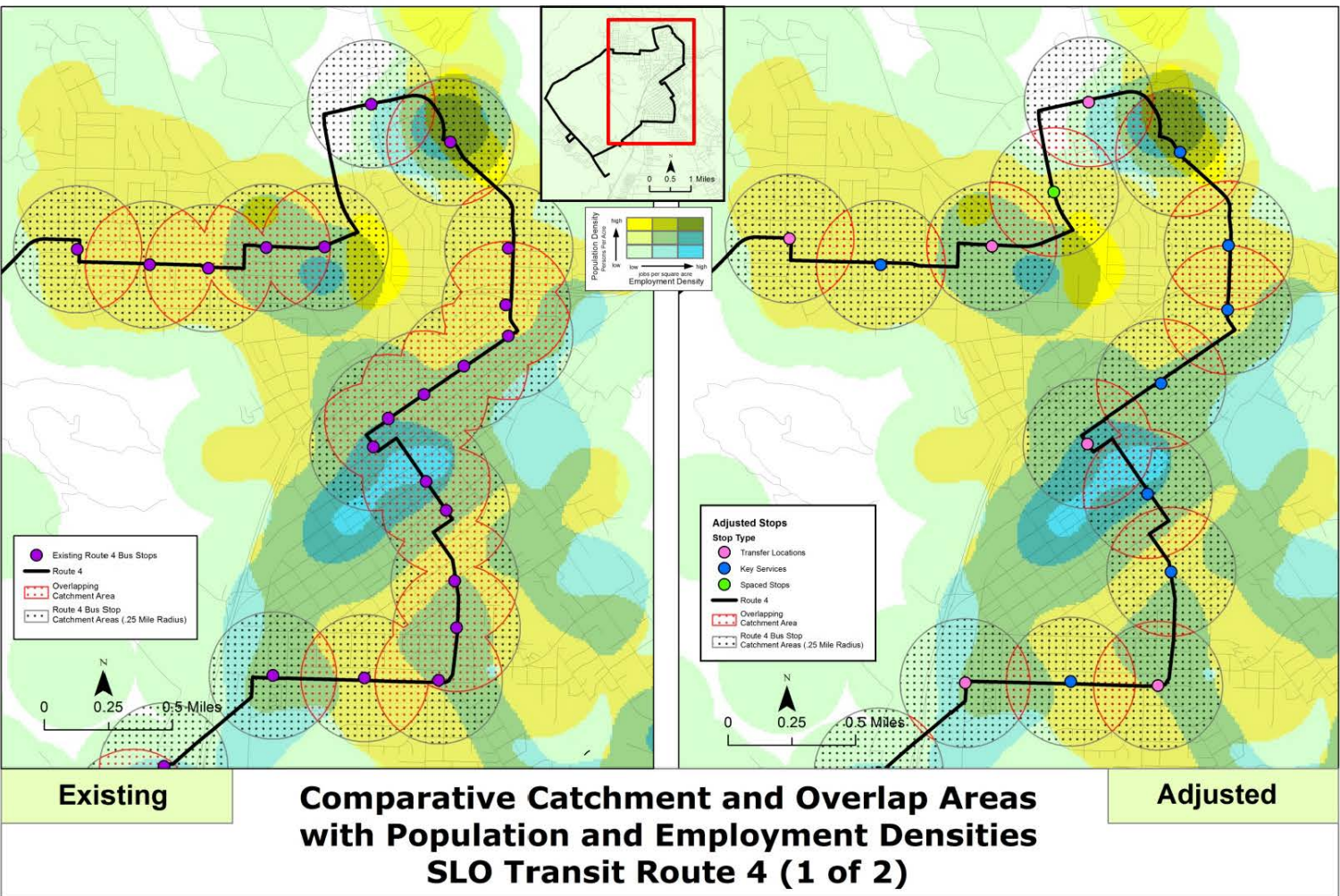
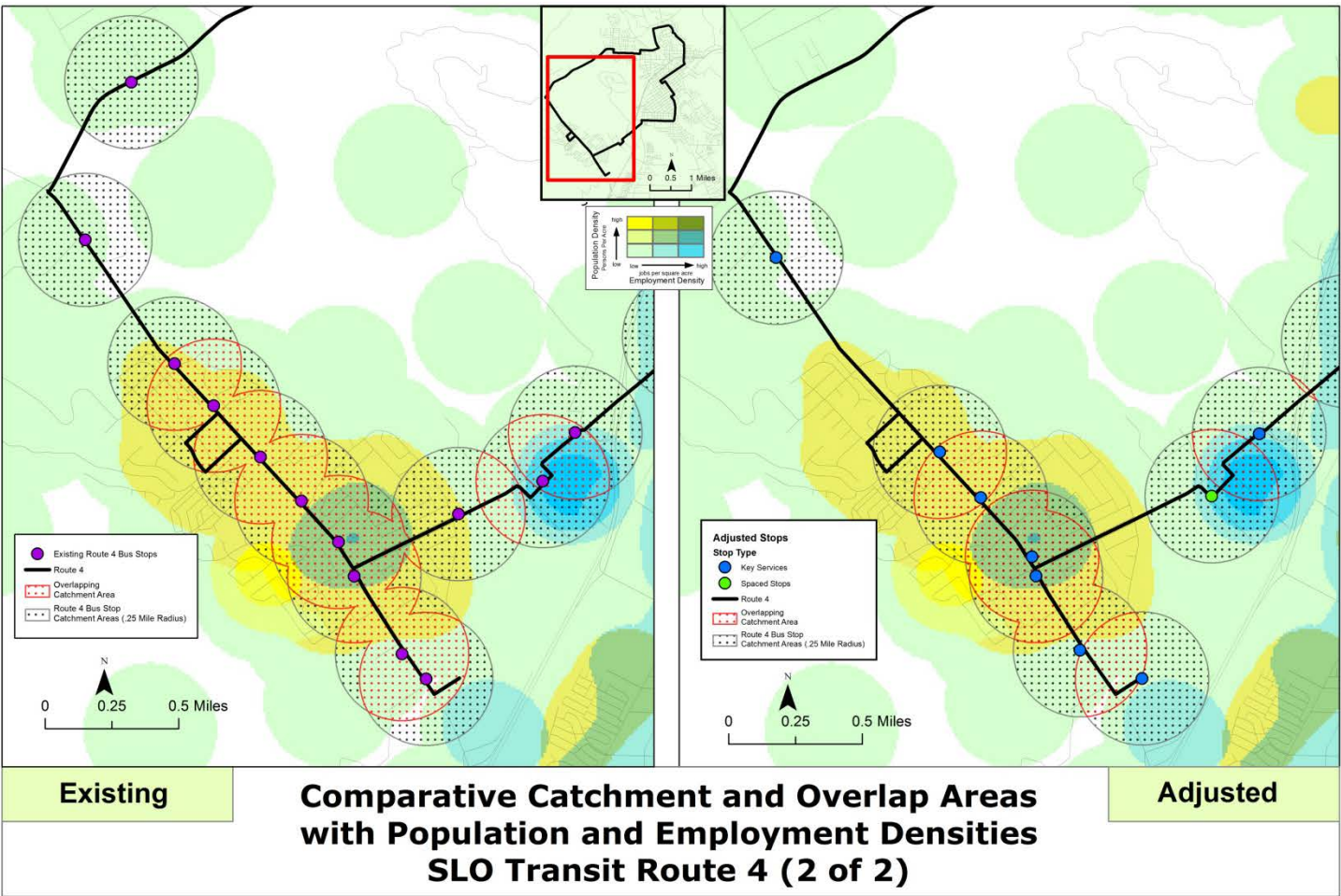


Figure 5-6: Comparative Buffer Overlaps vs. Activity Centers along Route 4 (2 of 2)



## 6.0 Application: Suburban Routes in San Luis Obispo County

### 6.1 Application Process for RTA Routes 9 and 10

Two RTA routes are presented together in this section because one is effectively a continuation of the other as they both traverse the entire north to south extent of San Luis Obispo County. The two routes connect with each other at the transit center in downtown, San Luis Obispo. Together, they provide regional public transit service that inter-connects most of the small cities in the county along the north-south, US 101 corridor.

#### 6.1.1 Early Steps

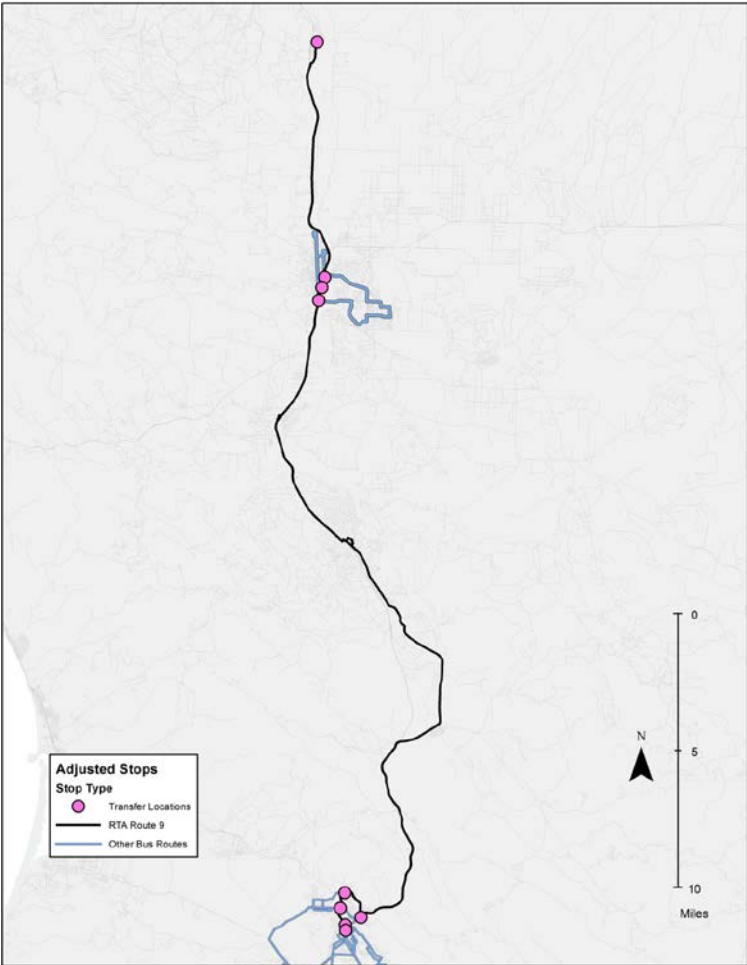
The early steps of the application process for RTA Routes 9 and 10 are similar to what was presented in the illustrative case in Section 4. This section focuses on analysis of the match and the accessibility between activity concentrations and stop locations of these case study routes. Additional information on the early steps is included in Appendix 6-1.

#### 6.1.2 Other Key Stop Placement Steps

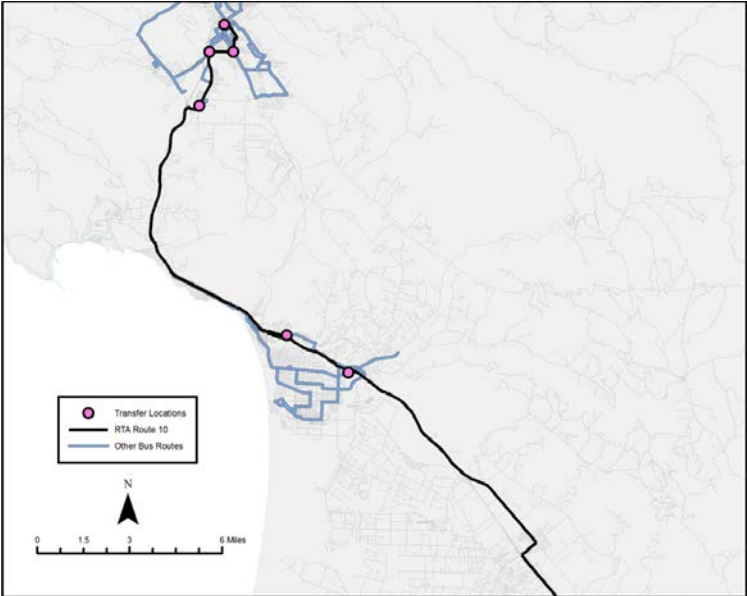
The other key stop placement steps of the application process for RTA Routes 9 and 10 are similar to what was presented for the illustrative case in Section 4. These included marking locations for the following:

- a. Transfer opportunities (in pink dots on Figures 6-1);
- b. Service and activity centers (in blue dots on Figures 6-2);
- c. Target distance separation of 0.5 mile for a walk access of 0.25 mile to nearest stop (in green dots on Figures 6-3).
- d. Then superfluous stops were removed or re-positioned to eliminate excessive overlapping of 0.25-mile buffers around stops while taking into account population and employment densities.

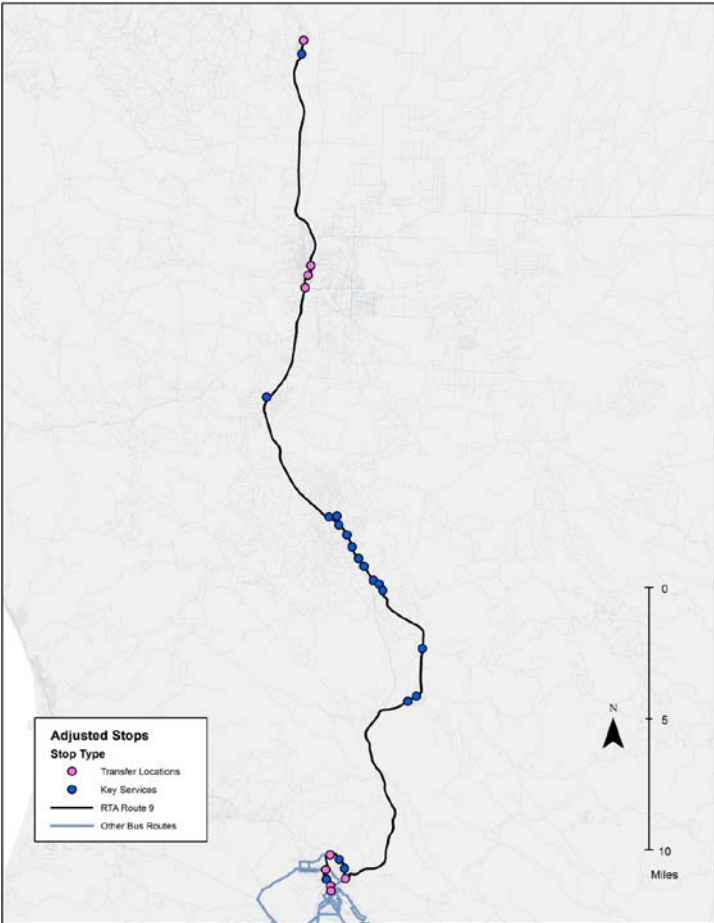
**Figure 6-1a: Potential Transfer Points along RTA Route 9**



**Figure 6-1b: Potential Transfer Points along RTA Route 10**



**Figure 6-2a: Key Service and Facility Locations along RTA Route 9**



**Figure 6-2b: Key Service and Facility Locations along RTA Route 10**

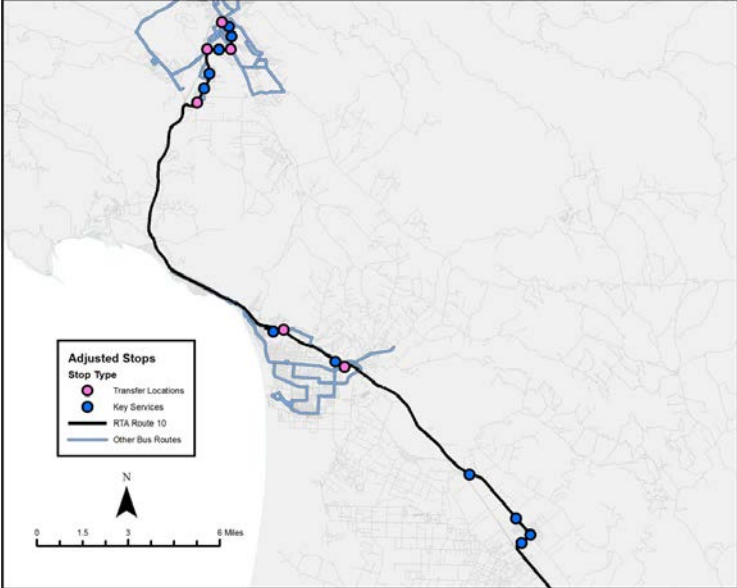




Figure 6-3a: Complete Placement of Stops along RTA Route 9

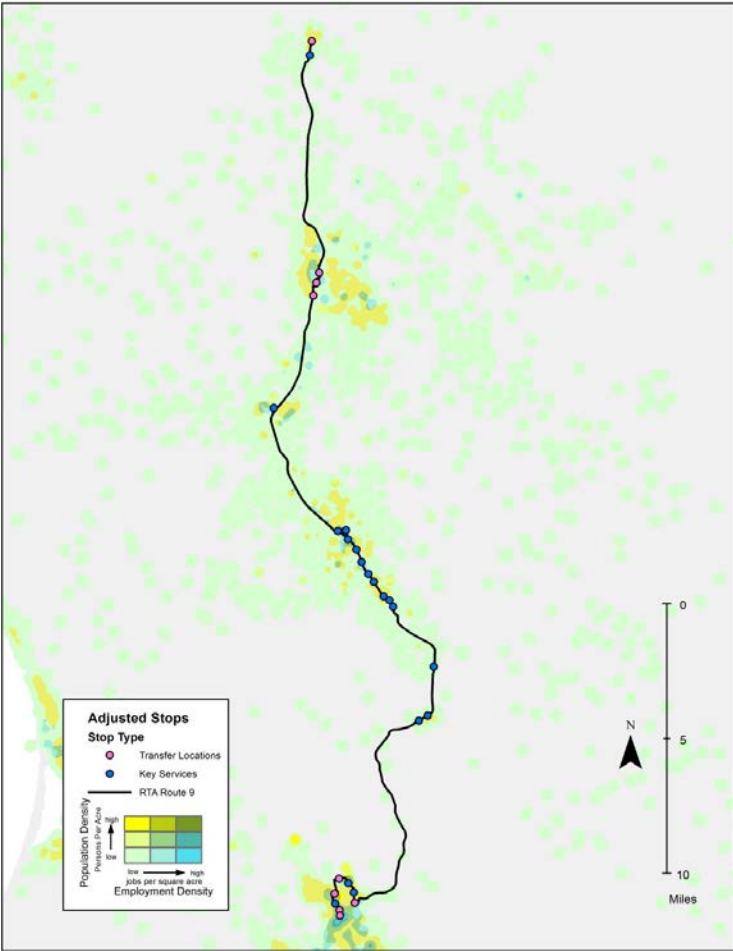
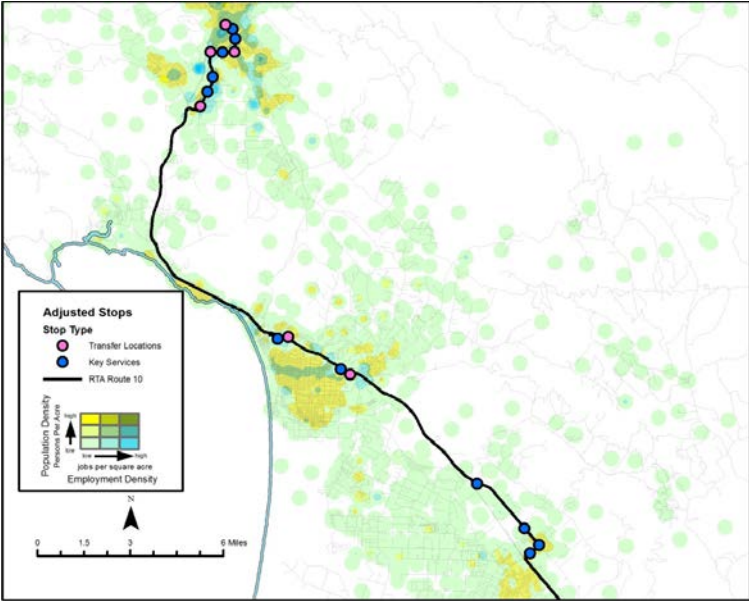


Figure 6-3b: Complete Placement of Stops along RTA Route 10



## **6.2 Analysis of Accessibility to SLO Transit Route 9**

RTA Route 9 had 30 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.25-mile buffer distances (0.5-mile diameter), is 4.7 square miles of which 1.0 square mile of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 21 percent overlap in catchment areas of stop locations. Figures 6-4 show buffer overlaps under existing conditions. It is noteworthy that overlaps occur in three segments of the route. The first and second sets occur within the communities of Atascadero and Santa Margarita respectively through which non-express runs provide local service. The third set occurs within the City of San Luis Obispo.

Applying the procedure of this study would result in 27 stop locations with a total coverage area of 4.7 square miles, which is the same as for the existing stops. Of that coverage area, 0.57 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 12 percent or approximately half of the existing condition. Figures 6-4 also show buffer overlaps under adjusted conditions.

Figures 6-4a through 6-4e show zoomed-in views of sections of RTA Route 9 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 6-5a through 6-5e show the same comparative overlap information superimposed over a base map of activity concentrations along the corridor. Appendix 6-2 has details of the procedure for creating a composite density map of population and employment concentrations.

Figure 6-4a: Comparative Buffer Overlaps along RTA Route 9 (1 of 5)

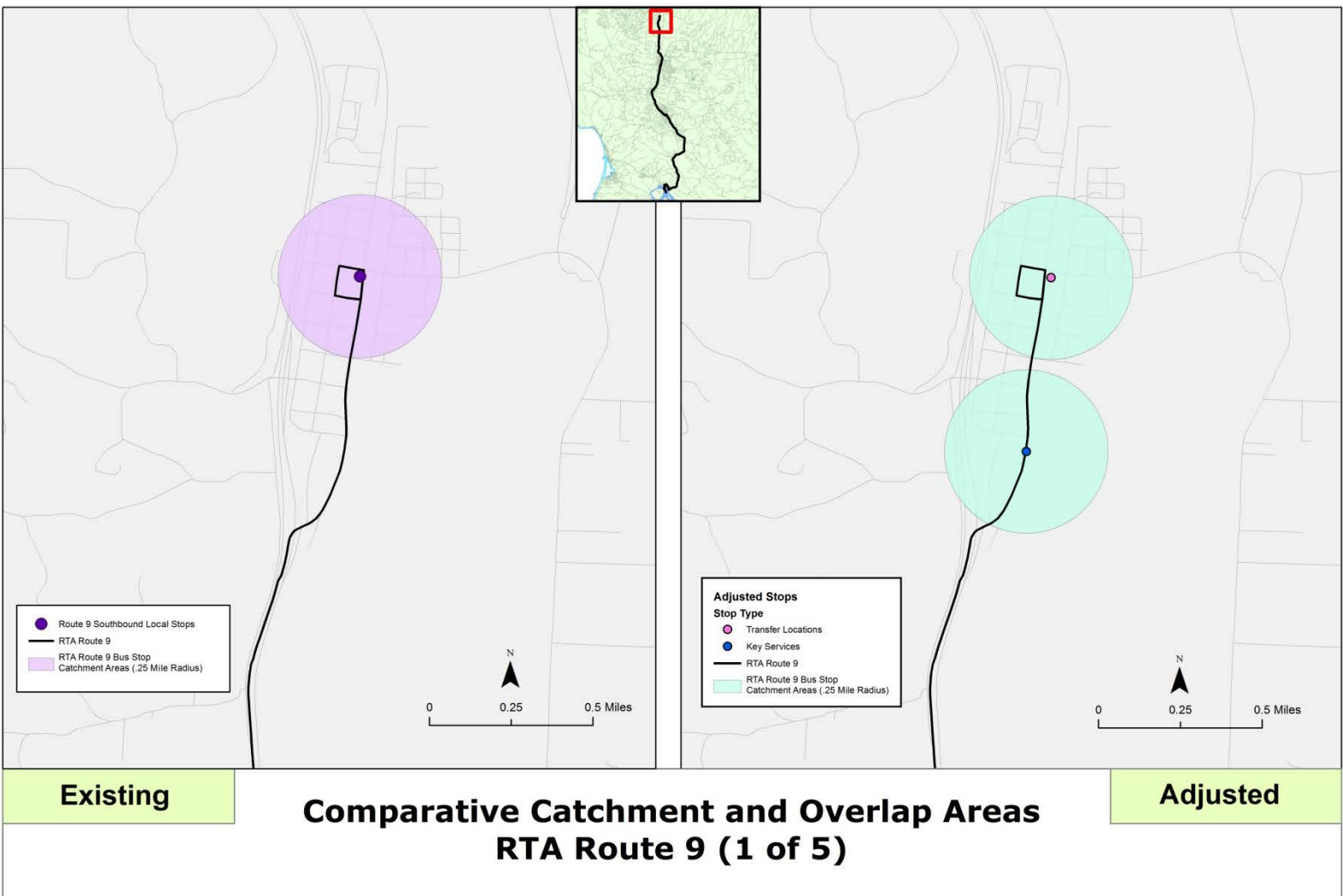


Figure 6-4b: Comparative Buffer Overlaps along RTA Route 9 (2 of 5)

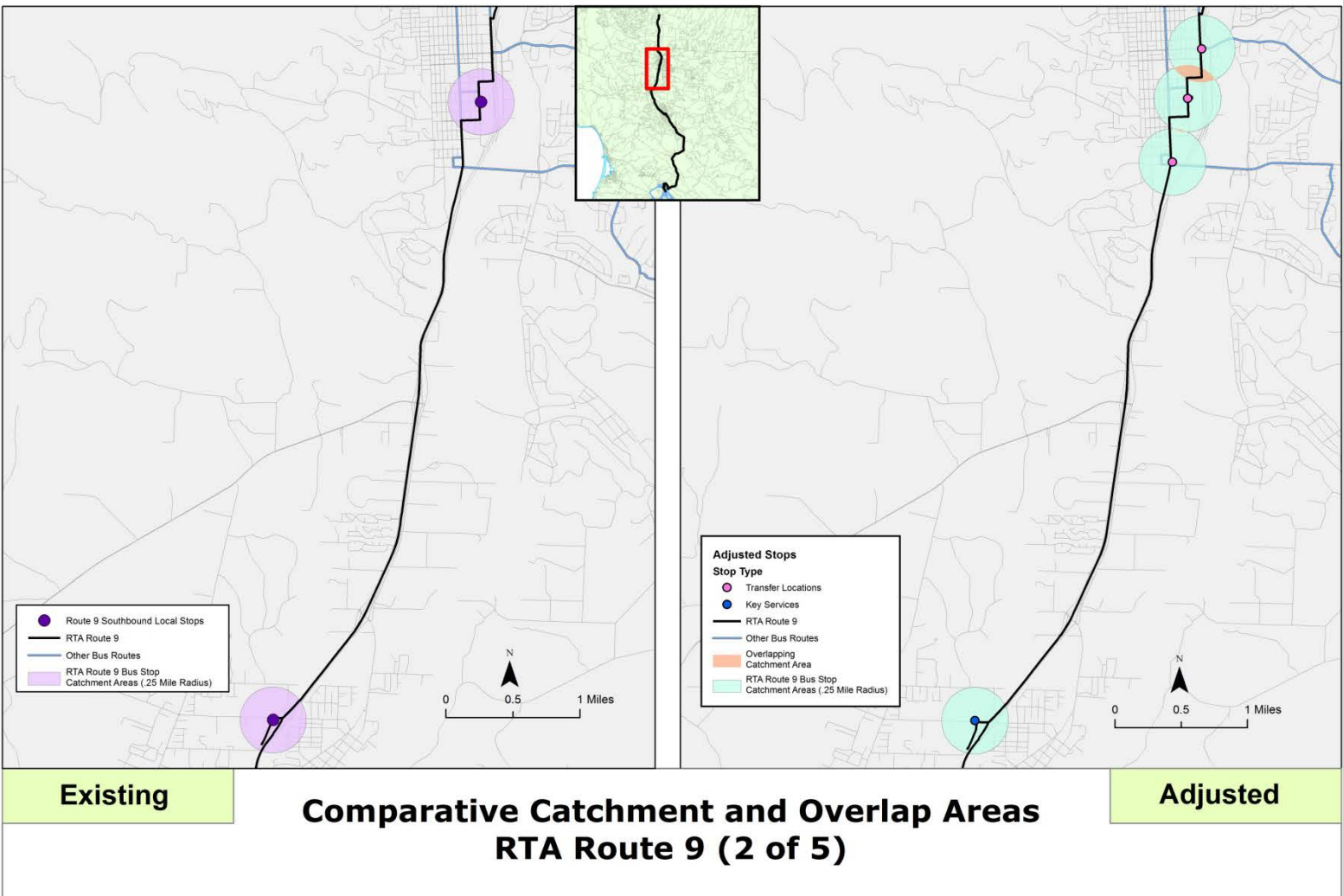


Figure 6-4c: Comparative Buffer Overlaps along RTA Route 9 (3 of 5)

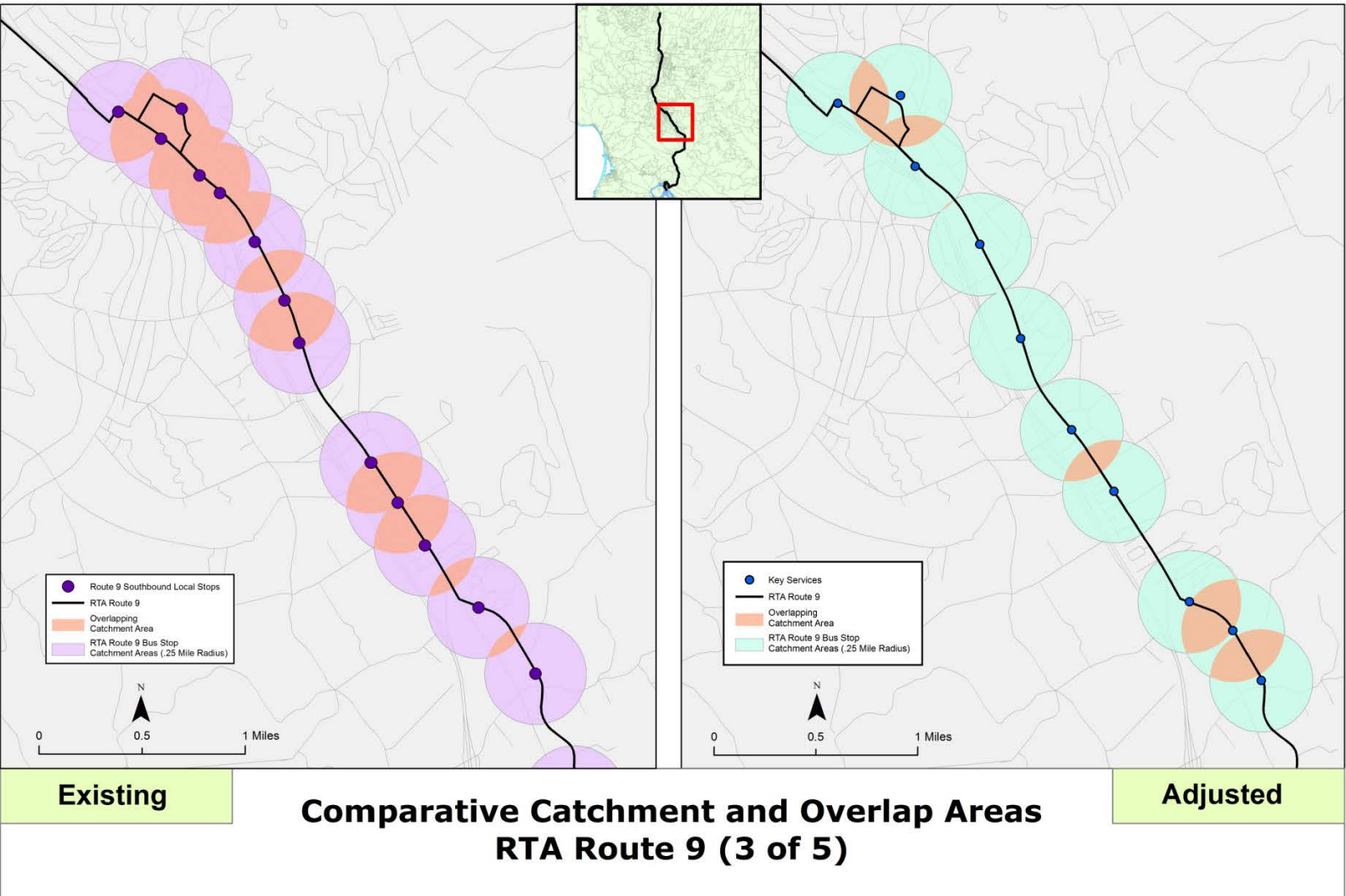


Figure 6-4d: Comparative Buffer Overlaps along RTA Route 9 (4 of 5)

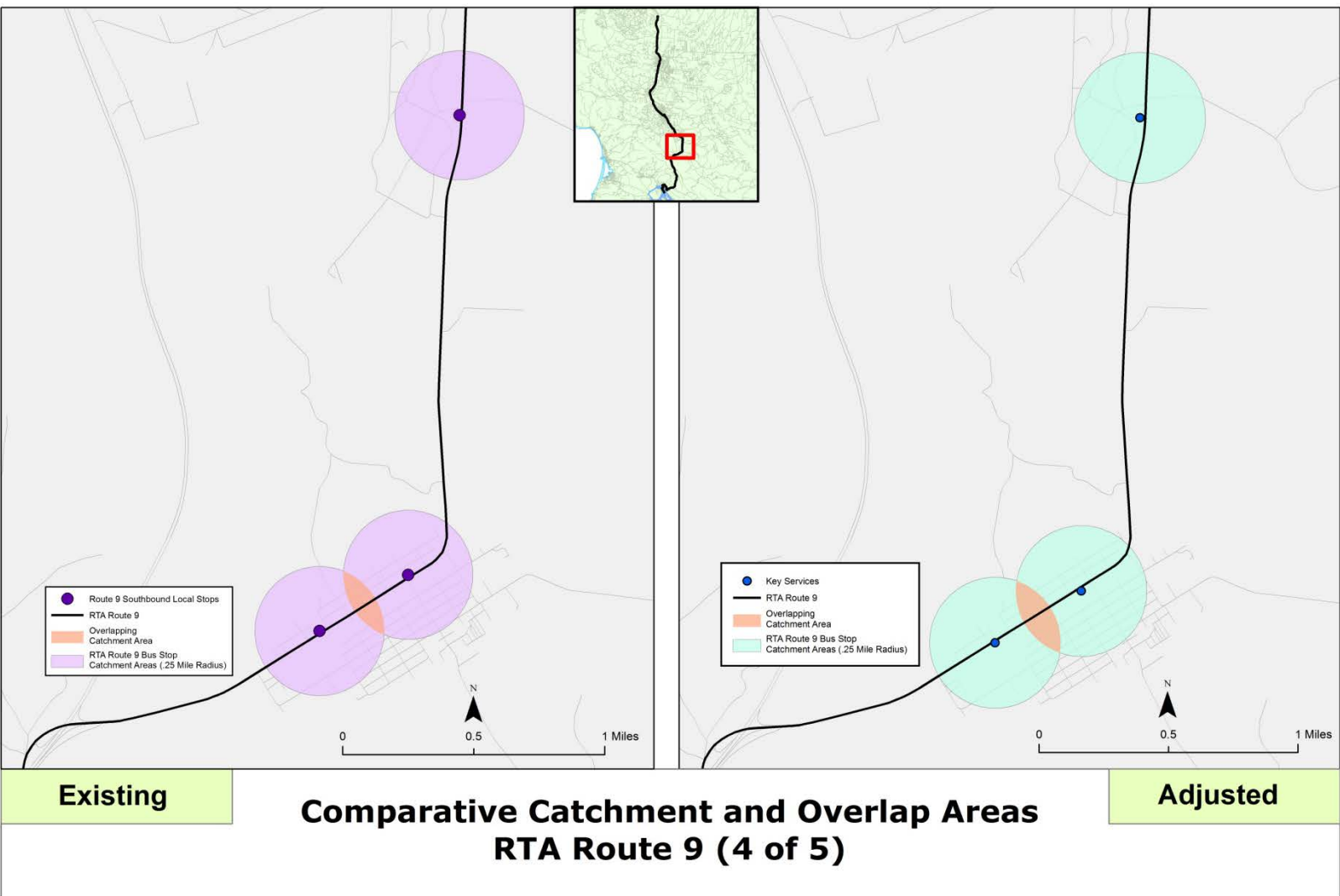


Figure 6-4e: Comparative Buffer Overlaps along RTA Route 9 (5 of 5)

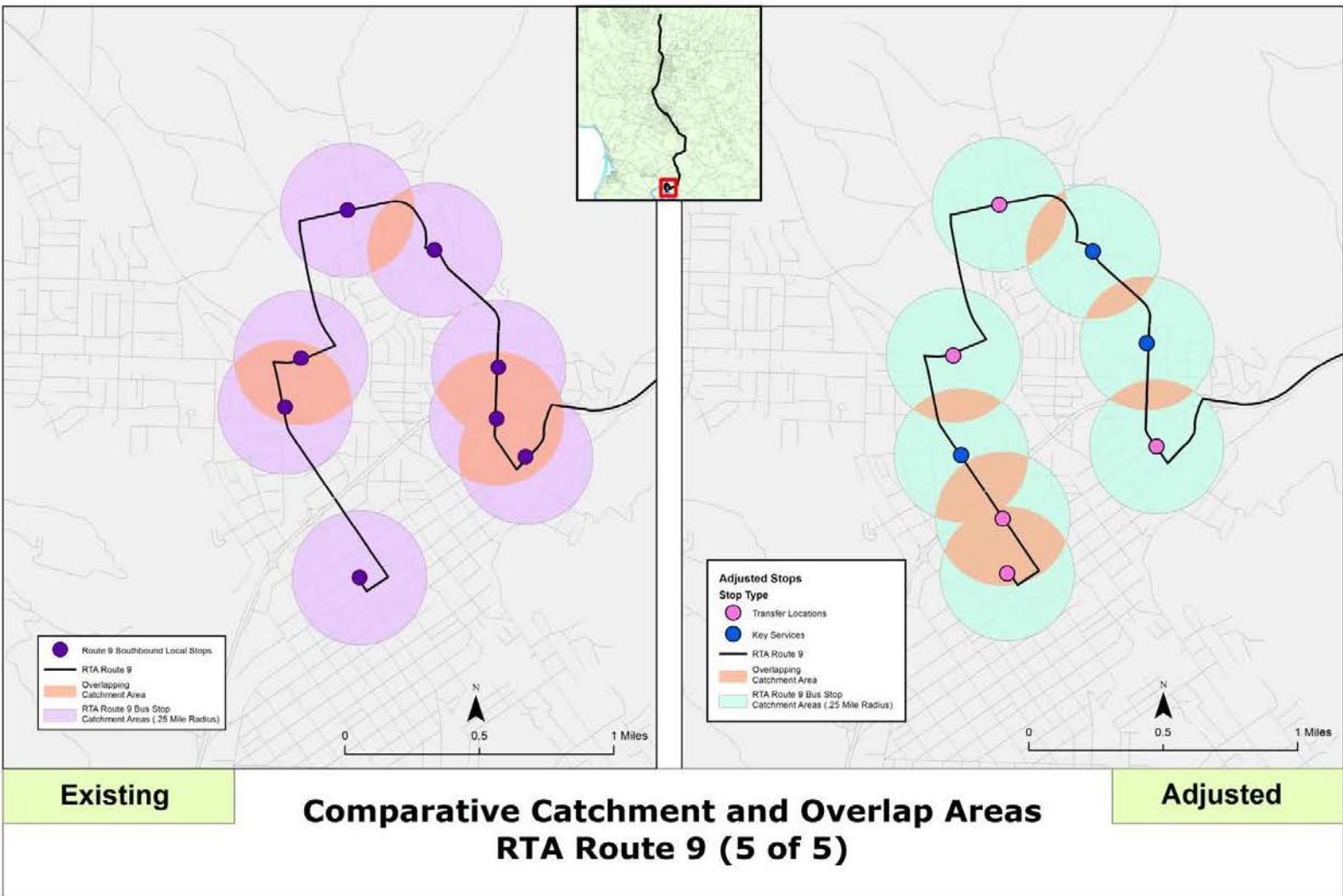


Figure 6-5a: Comparative Buffer Overlaps vs. Activity Centers along RTA Route 9 (1 of 5)

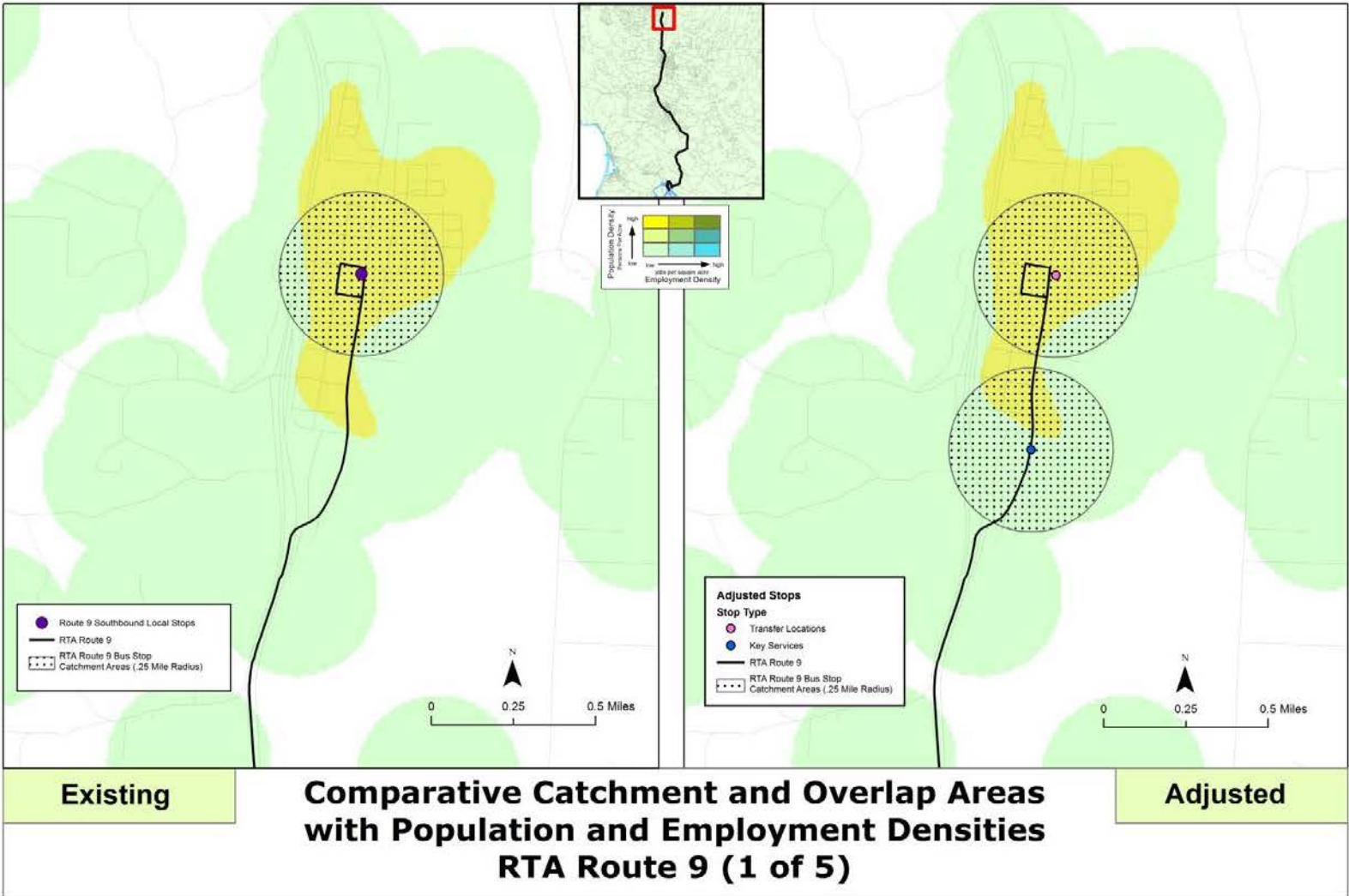




Figure 6-5b: Comparative Buffer Overlaps vs. Activity Centers along RTA Route 9 (2 of 5)

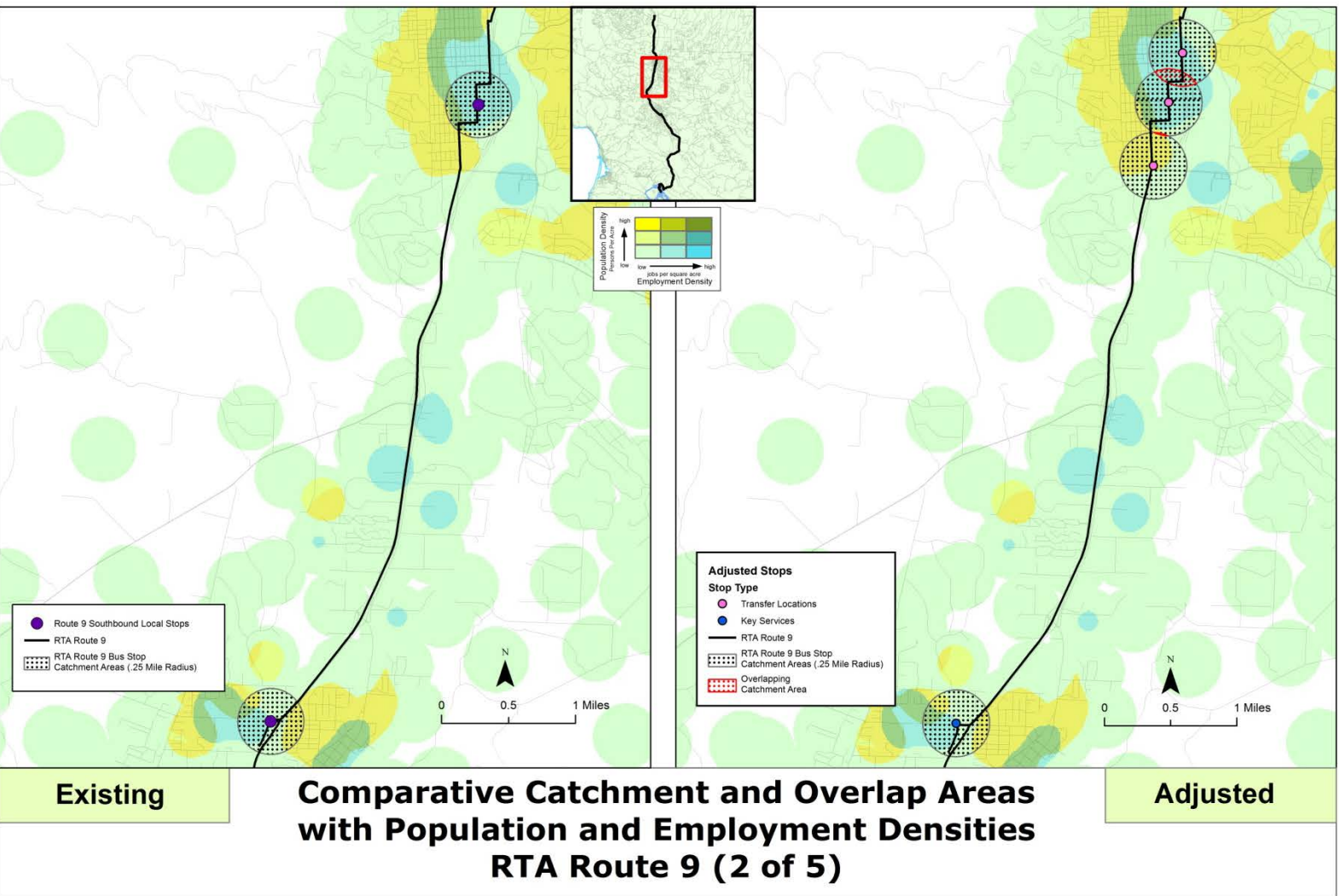


Figure 6-5c: Comparative Buffer Overlaps vs. Activity Centers along RTA Route 9 (3 of 5)

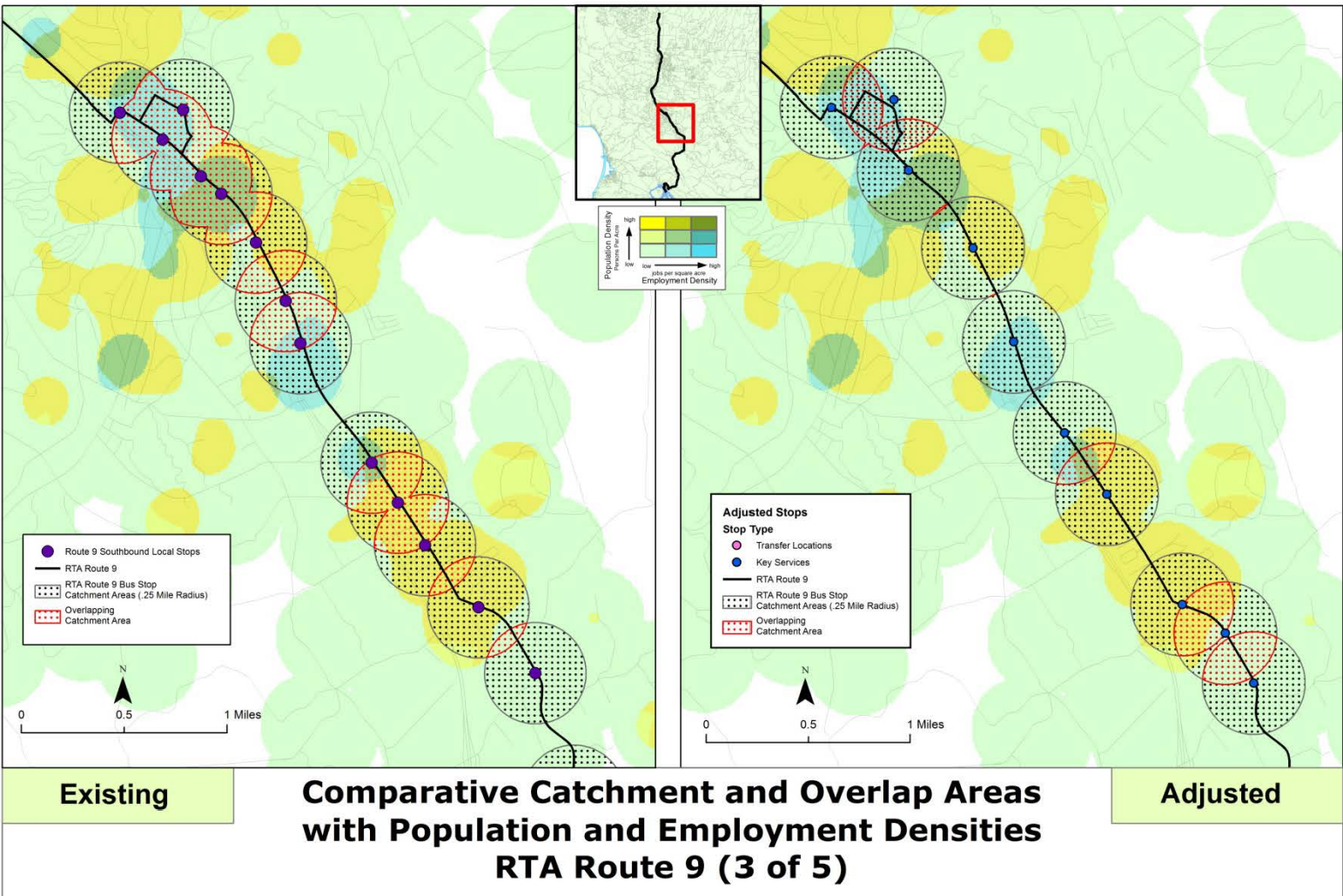


Figure 6-5d: Comparative Buffer Overlaps vs. Activity Centers along RTA Route 9 (4 of 5)

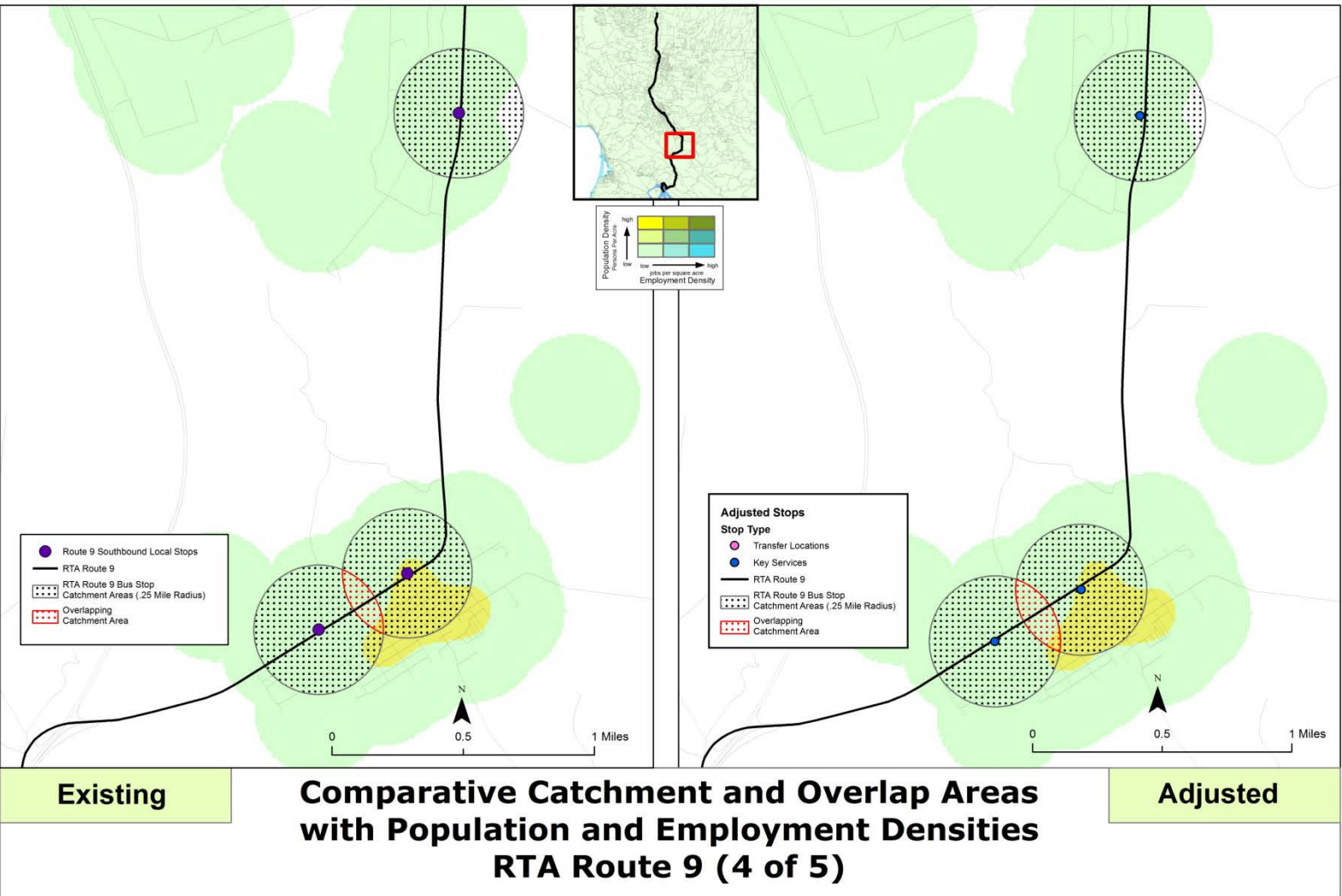
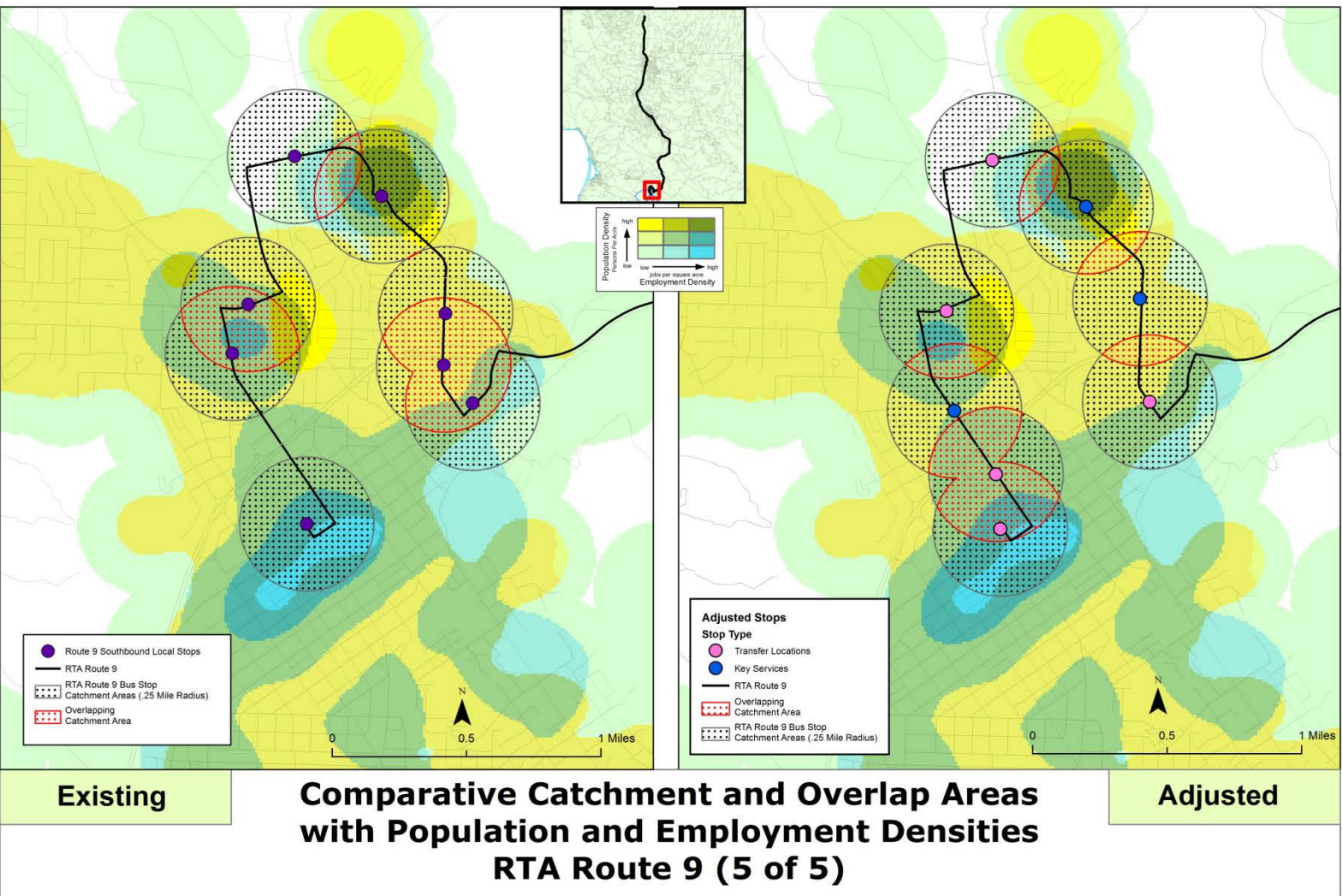


Figure 6-5e: Comparative Buffer Overlaps vs. Activity Centers along RTA Route 9 (5 of 5)



### **6.3 Analysis of Accessibility to RTA Route 10**

RTA Route 10 had 25 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.25-mile buffer distances (0.5-mile diameter), is 2.97 square miles of which 0.65 square mile of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 22 percent overlap in catchment areas of stop locations. Figures 6-6 show buffer overlaps under existing conditions.

Applying the procedure of this study would result in 17 stop locations with a total coverage area of 3.06 square miles, which is approximately the same as for the existing stops. Of that coverage area, 0.28 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 9 percent or approximately half of the existing condition. Figures 6-6 show buffer overlaps under adjusted conditions.

Figures 6-6a through 6-6c present zoomed-in views of sections of RTA Route 10 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 6-7a through 6-7c show the same comparative overlap information superimposed over a base map of activity concentrations.

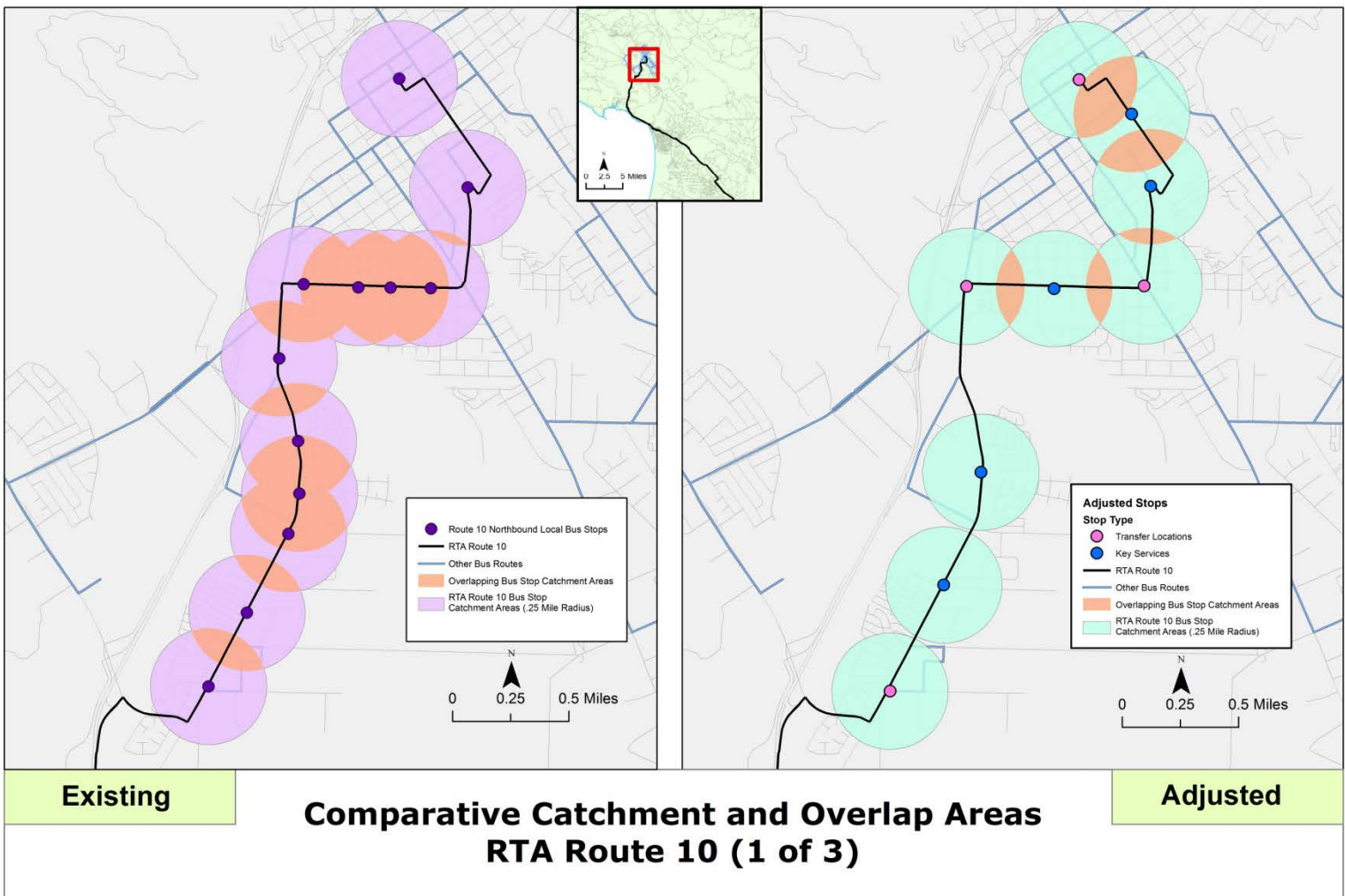


Figure 6-6a: Comparative Buffer Overlaps along RTA Route 10 (1 of 3)

Figure 6-6b: Comparative Buffer Overlaps along RTA Route 10 (2 of 3)

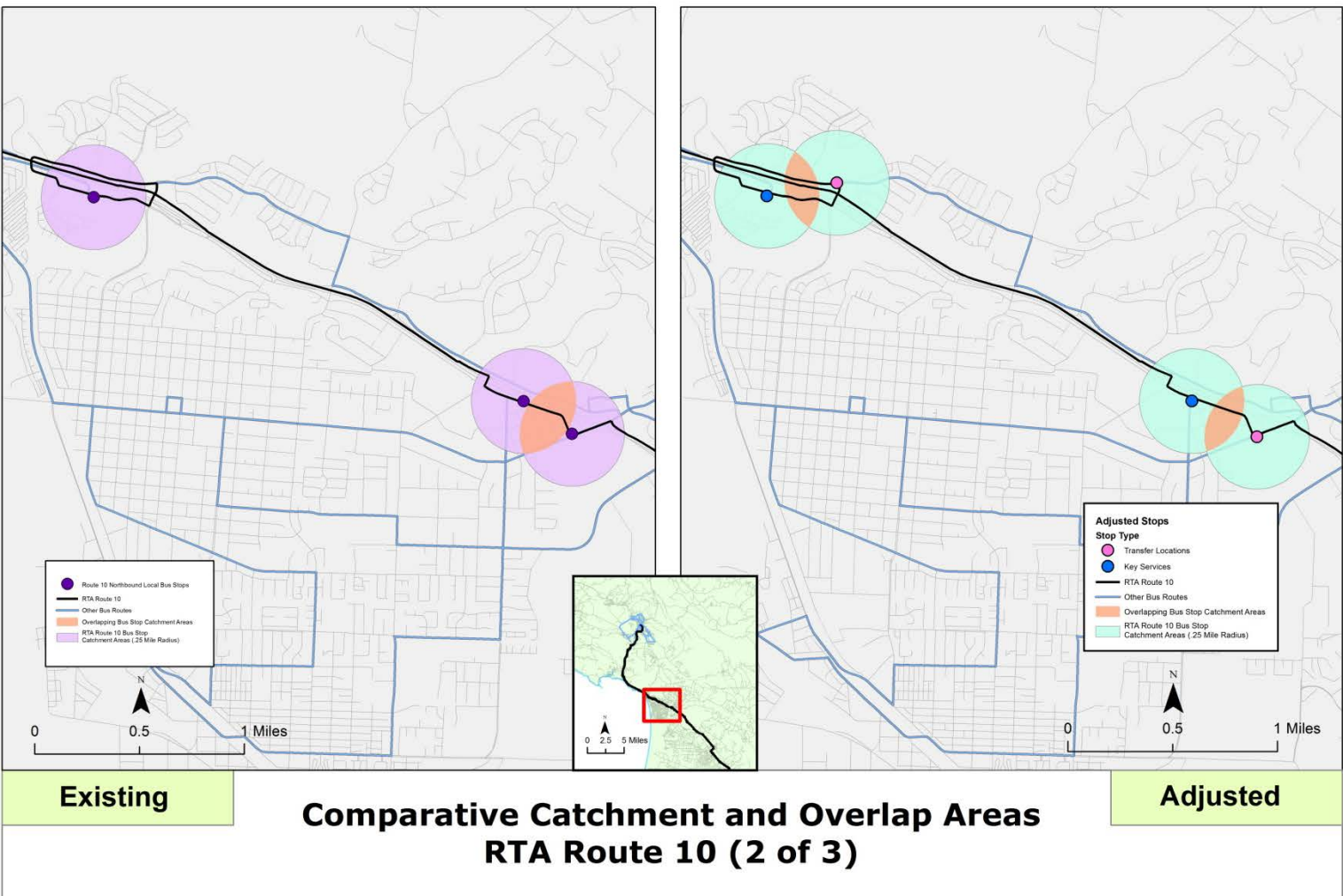


Figure 6-6c: Comparative Buffer Overlaps along RTA Route 10 (3 of 3)

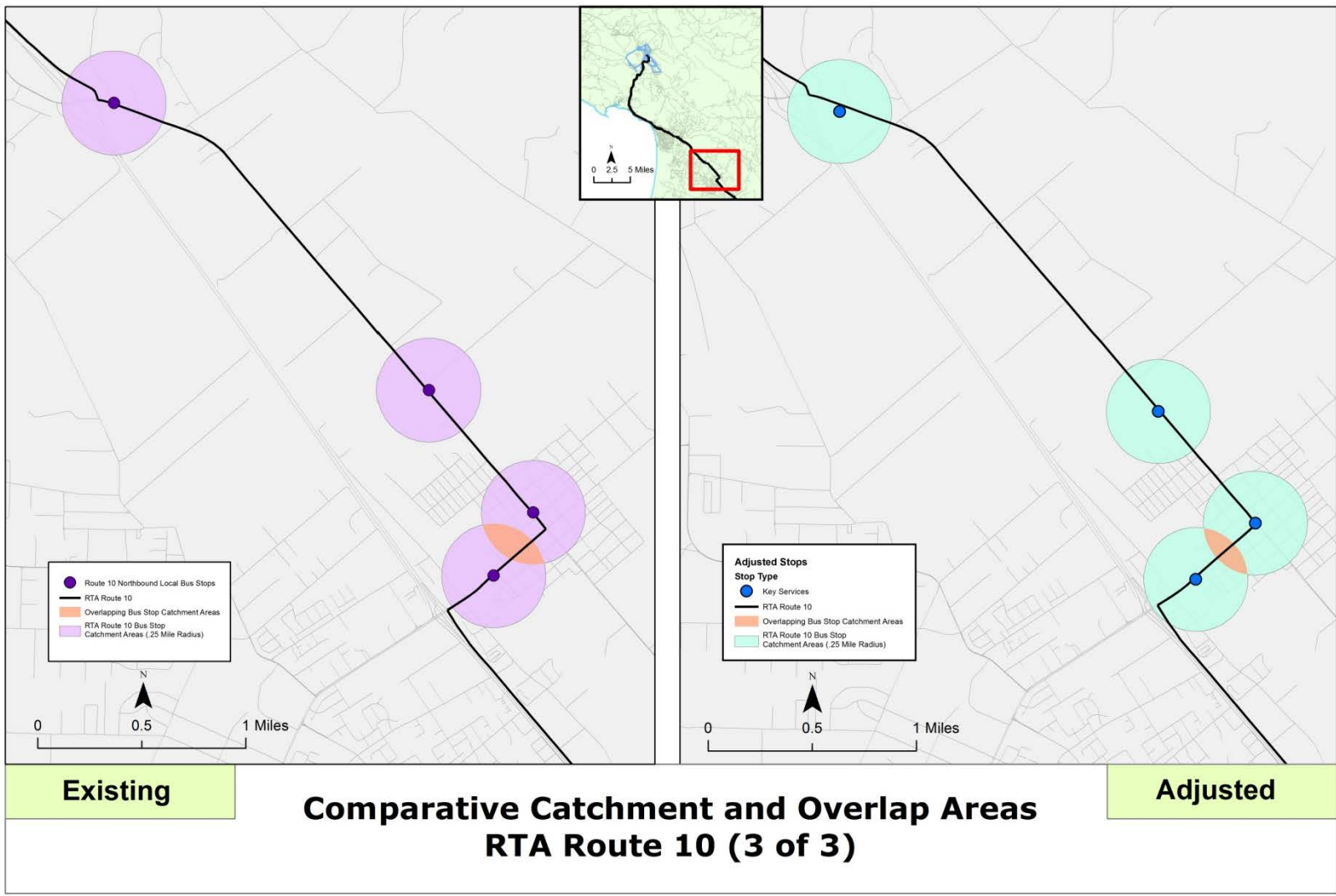




Figure 6-7a: Comparative Buffer Overlaps vs. Activity Centers on RTA Route 10 (1 of 3)

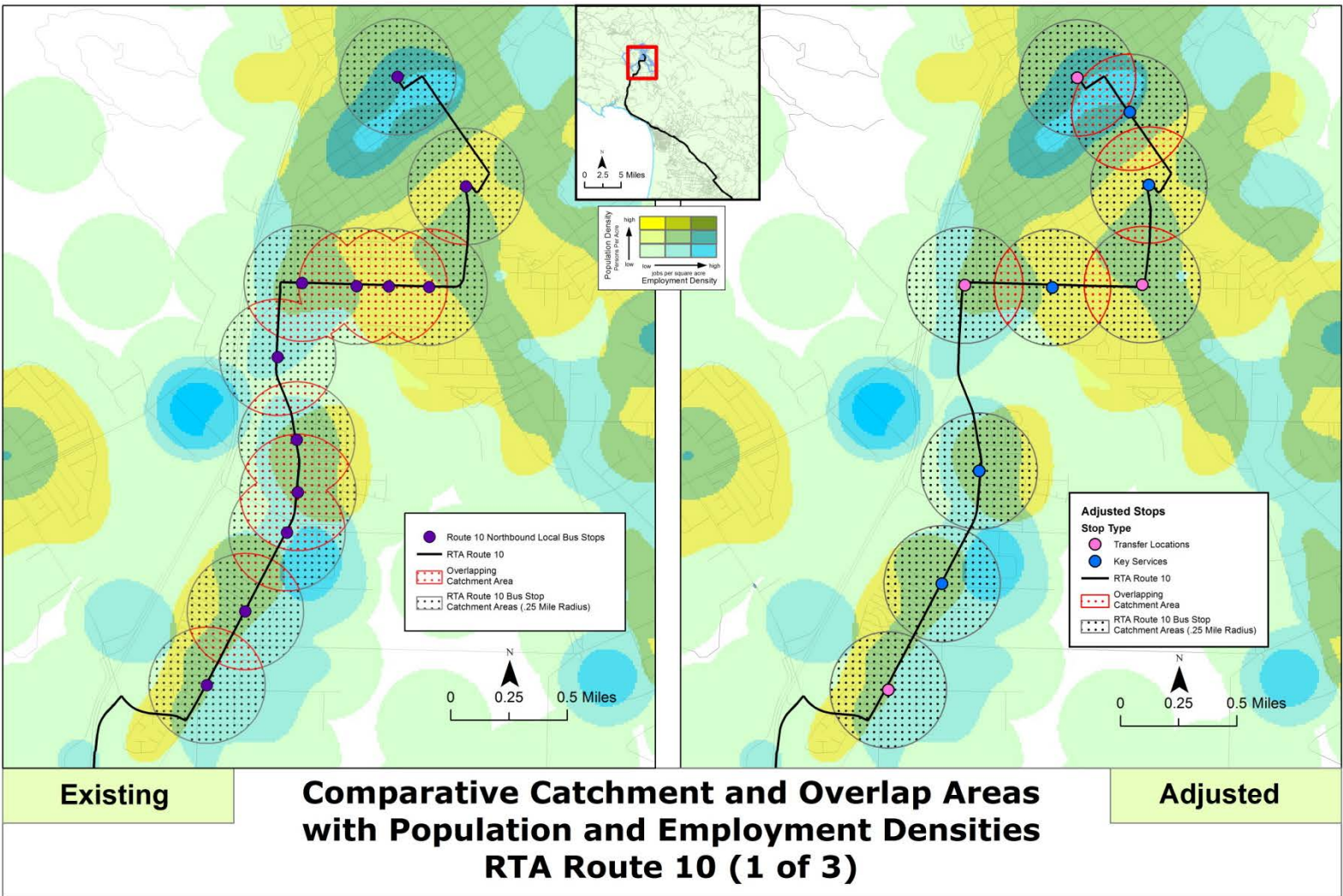
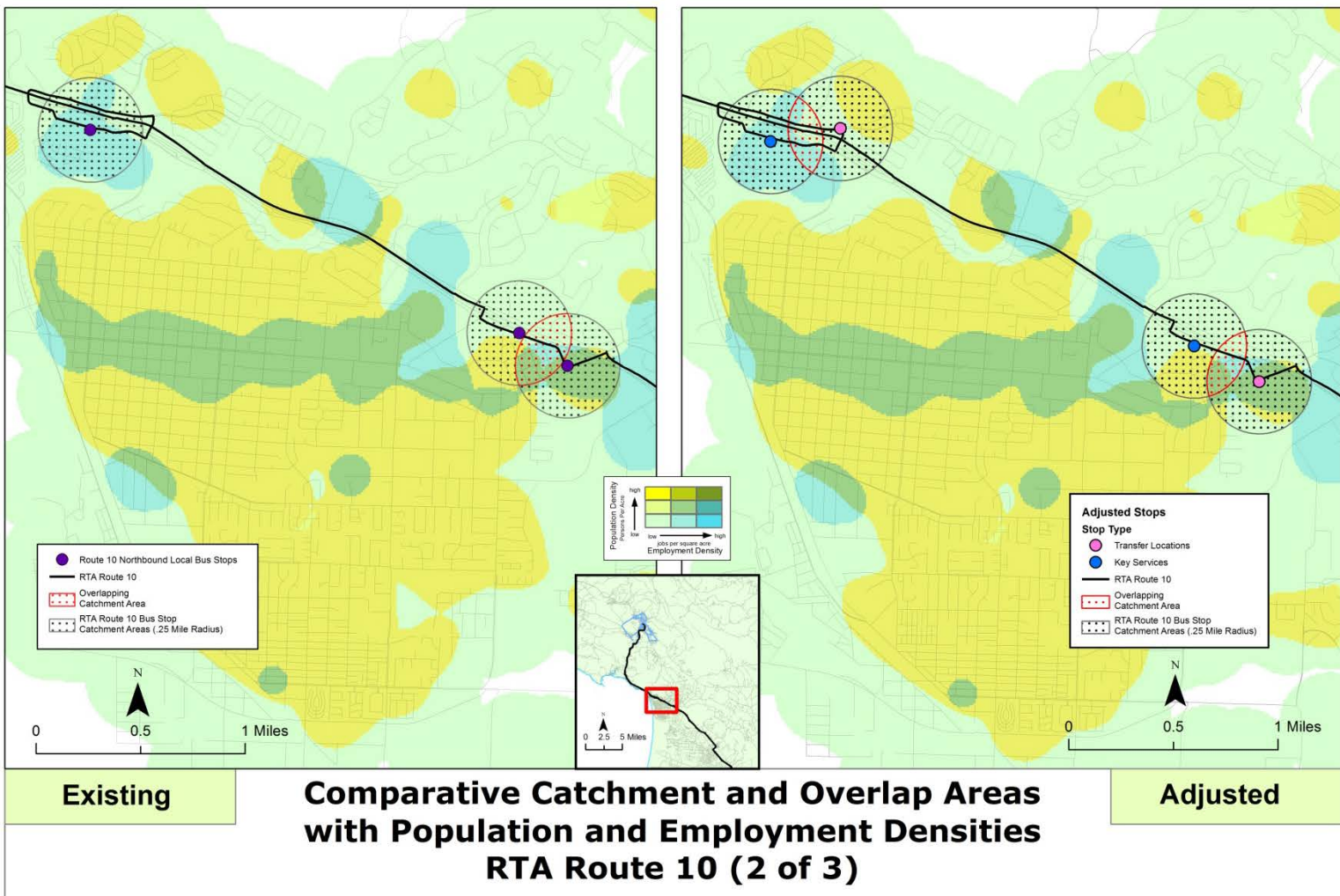


Figure 6-7b: Comparative Buffer Overlaps vs. Activity Centers on RTA Route 10 (2 of 3)





## 7.0 Application: Large Urban Area Routes in San Francisco

### 7.1 Application Process for SFMTA Routes 2, 49 and 71

Unlike the two RTA routes that form a continuation of service across San Luis Obispo County, the SFMTA routes are individual as each one traverses the City along a different corridor. They variously serve north-south and east-west movements across the city of San Francisco.

#### 7.1.1 Early Steps

The early steps of the application process for SFMTA Routes 2, 49 and 71 are similar to what was presented in the illustrative case in Section 4. This section focuses on analysis of the match and the accessibility between activity concentrations and stop locations of these case study routes. Additional information on the early steps is included in Appendix 7-1.

#### 7.1.2 Other Key Stop Placement Steps

The other key stop placement steps of the application process for SFMTA Routes 2, 49 and 71 are similar to what was presented for the illustrative case in Section 4. These are presented in respective subsections and included marking locations for the following:

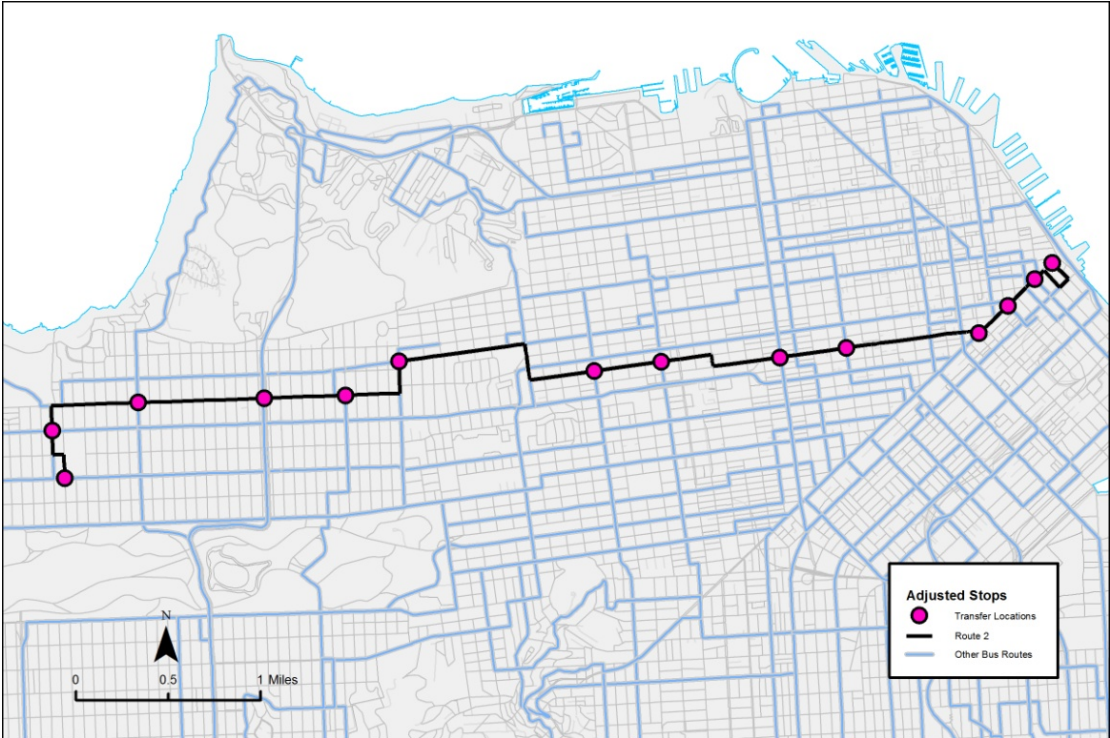
- a. Transfer opportunities (in pink dots);
- b. Service and activity centers (in blue dots);
- c. Target distance separation of 0.25 mile for a walk access of 0.125 mile to nearest stop (in green dots);
- d. Locations of steep grades (of 10% or more).
- e. Then superfluous stops were removed or re-positioned to eliminate excessive overlapping of 0.125-mile buffers around stops while taking into account population and employment densities. The relatively high density of San Francisco is reflected in the close separation of existing stop locations.

### 7.2 Analysis of Accessibility to SFMTA Route 2

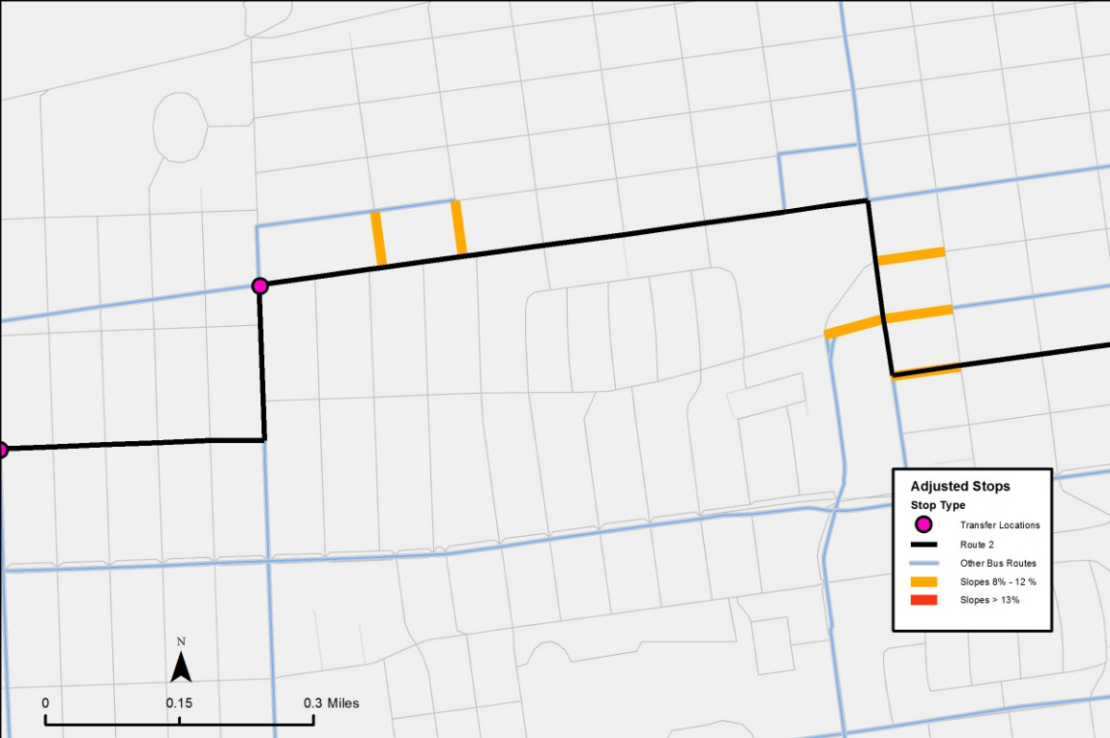
#### 7.2.1 Key Stop Placement Steps

Similar to previous applications of the procedure, major stops were identified in terms of transfer opportunities (Figure 7-1), steep grade segments (Figure 7-2) and target separation between stops (Figure 7-3).

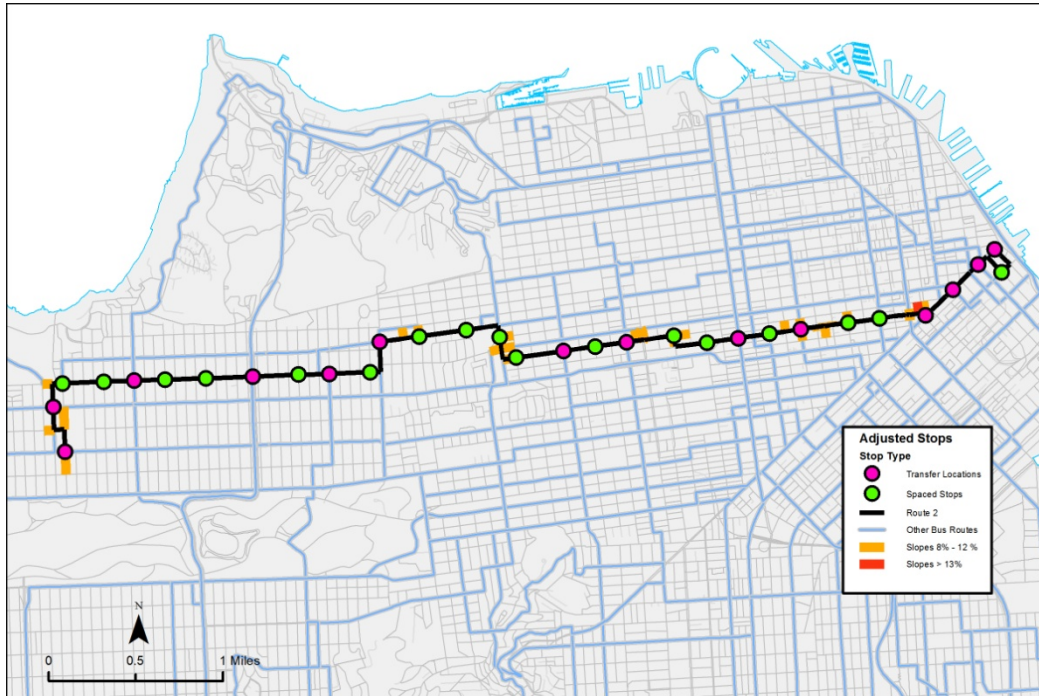
**Figure 7-1: Potential Transfer Points along SFMTA Route 2**



**Figure 7-2: Placement of Stops in Steep Grade Segments along SFMTA Route 2**



**Figure 7-3: Complete Placement of Stops along SFMTA Route 2**



### 7.2.2 Buffer Analysis

SFMTA Route 2 had 52 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.125-mile buffer distances (0.25-mile diameter), is 1.5 square miles of which 0.84 square mile of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 56 percent overlap in catchment areas of stop locations. Figures 7-4 show buffer overlaps under existing conditions in different segments of the route.

Applying the procedure of this study would result in 31 stop locations with a total coverage area of 1.34 square miles, which is approximately a 10 percent reduction compared to the existing stops. Of that coverage area, 0.16 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 12 percent or approximately one fifth of the existing condition. Figures 7-4 also show buffer overlaps under adjusted conditions for various segments of the route.

Figures 7-4a and 7-4b show zoomed-in views of sections of SFMTA Route 2 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 7-5a and 7-5b show the same comparative overlap information superimposed over a base map of activity concentrations along the corridor.

Figure 7-4a: Comparative Buffer Overlaps along SFMTA Route 2 (1 of 2)

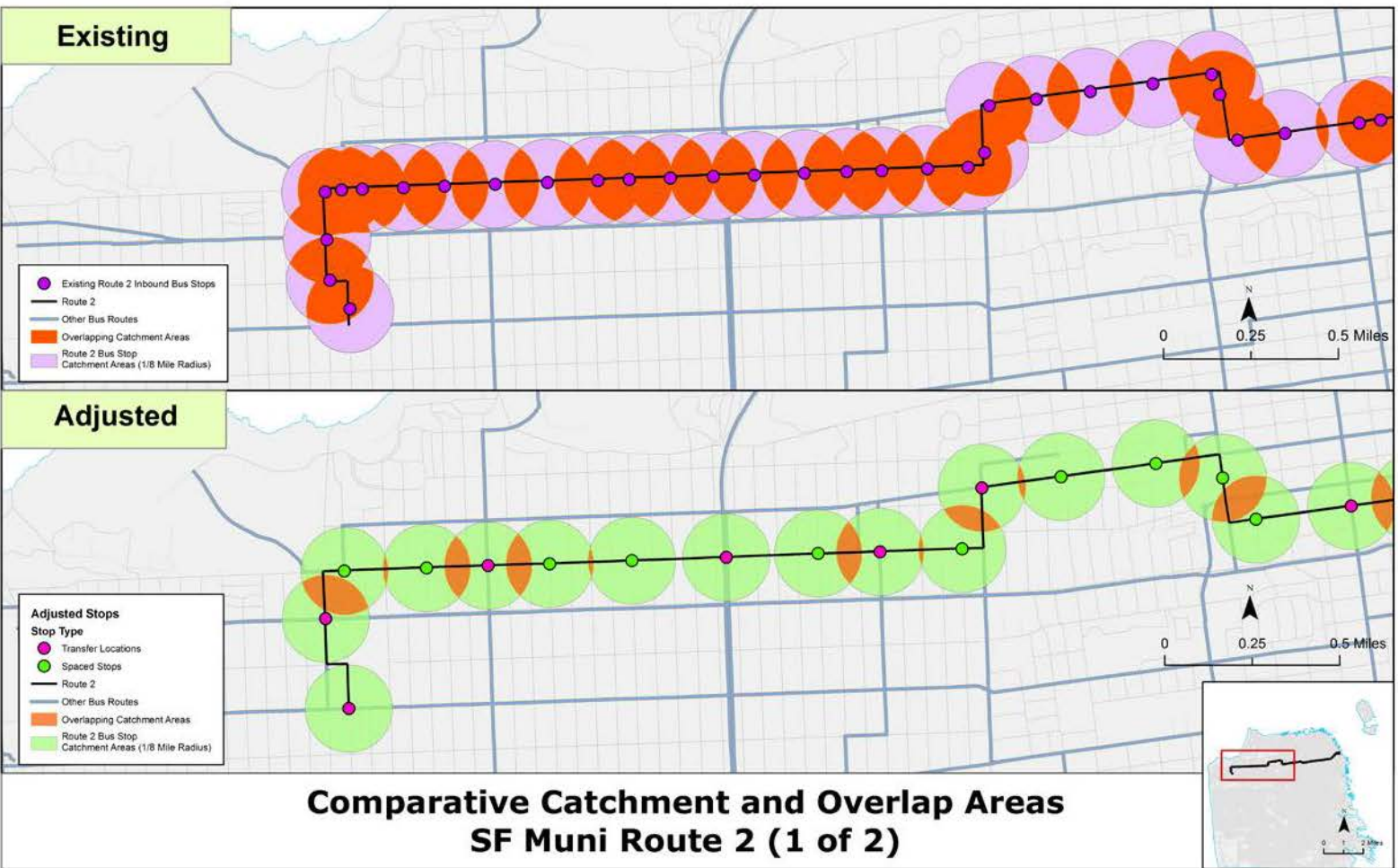


Figure 7-4b: Comparative Buffer Overlaps along SFMTA Route 2 (2 of 2)

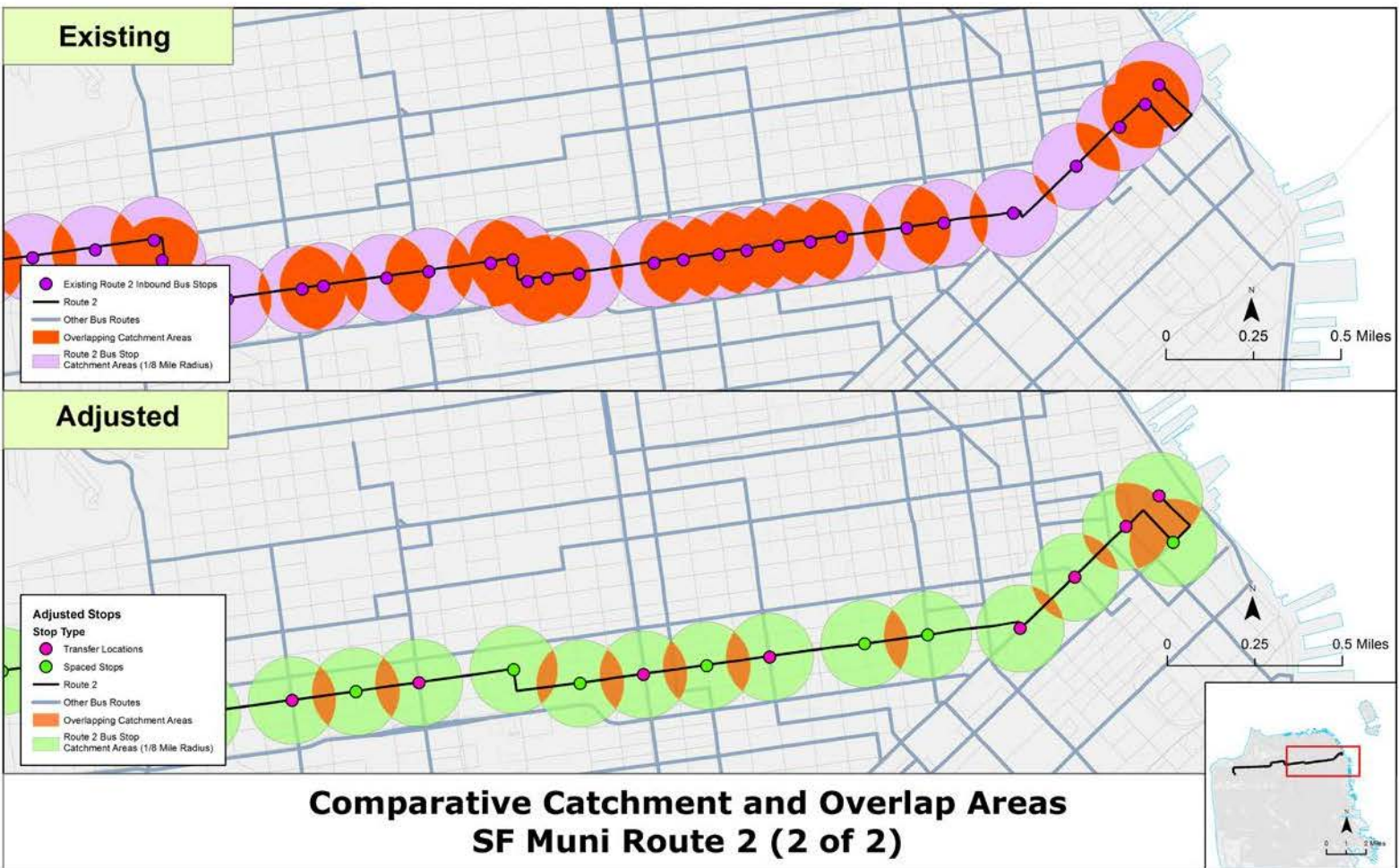




Figure 7-5a: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 2 (1 of 2)

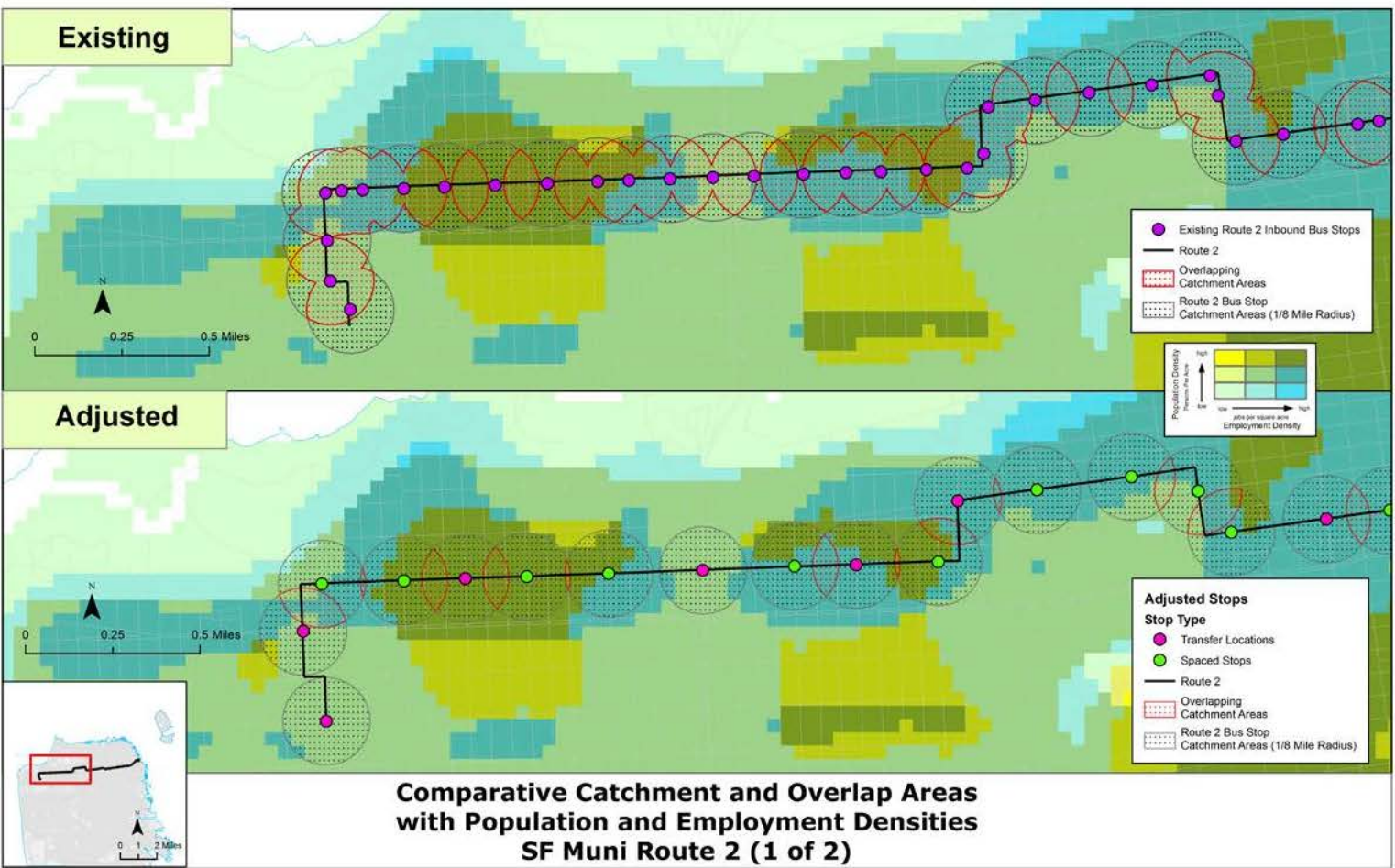
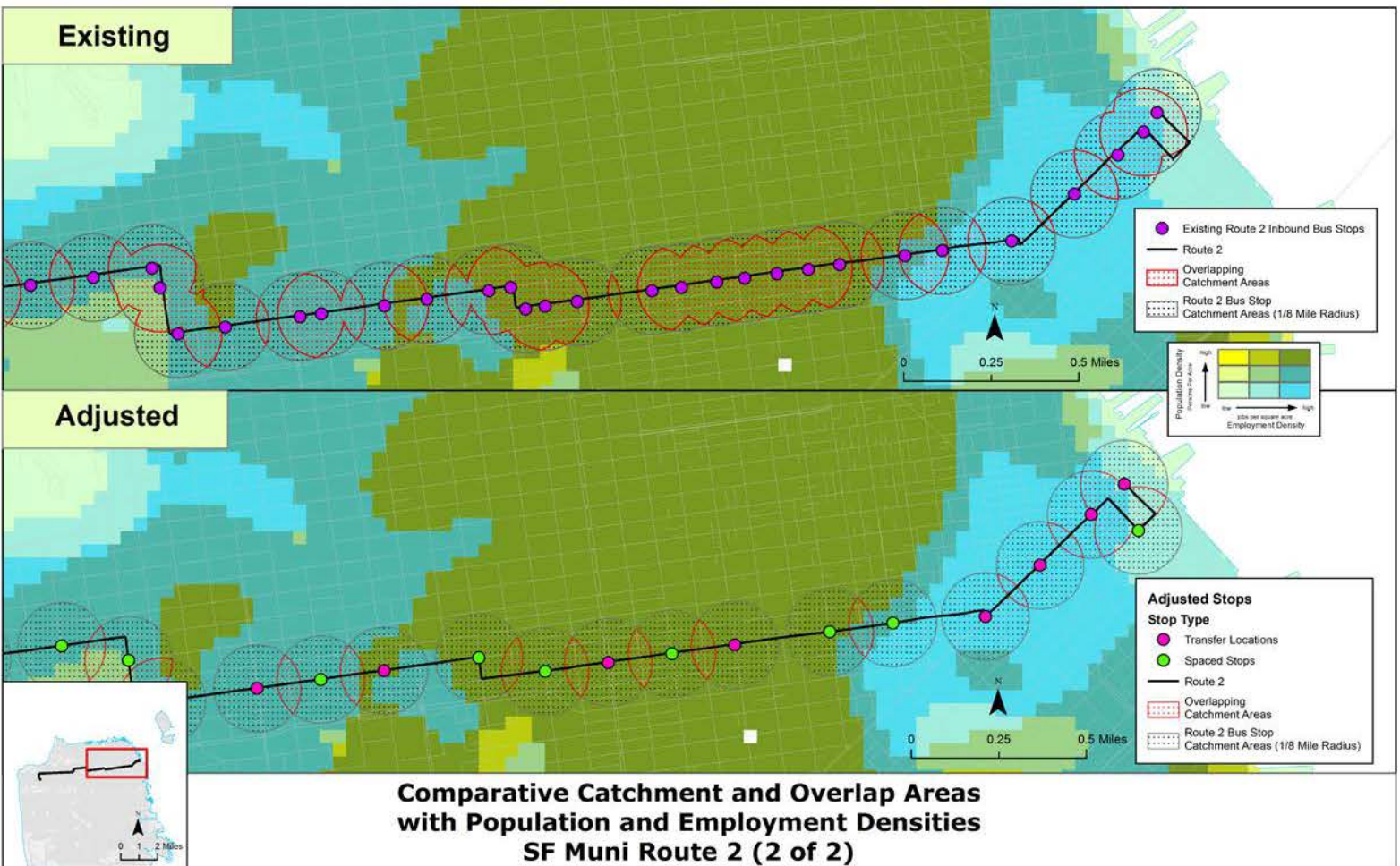


Figure 7-5b: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 2 (2 of 2)

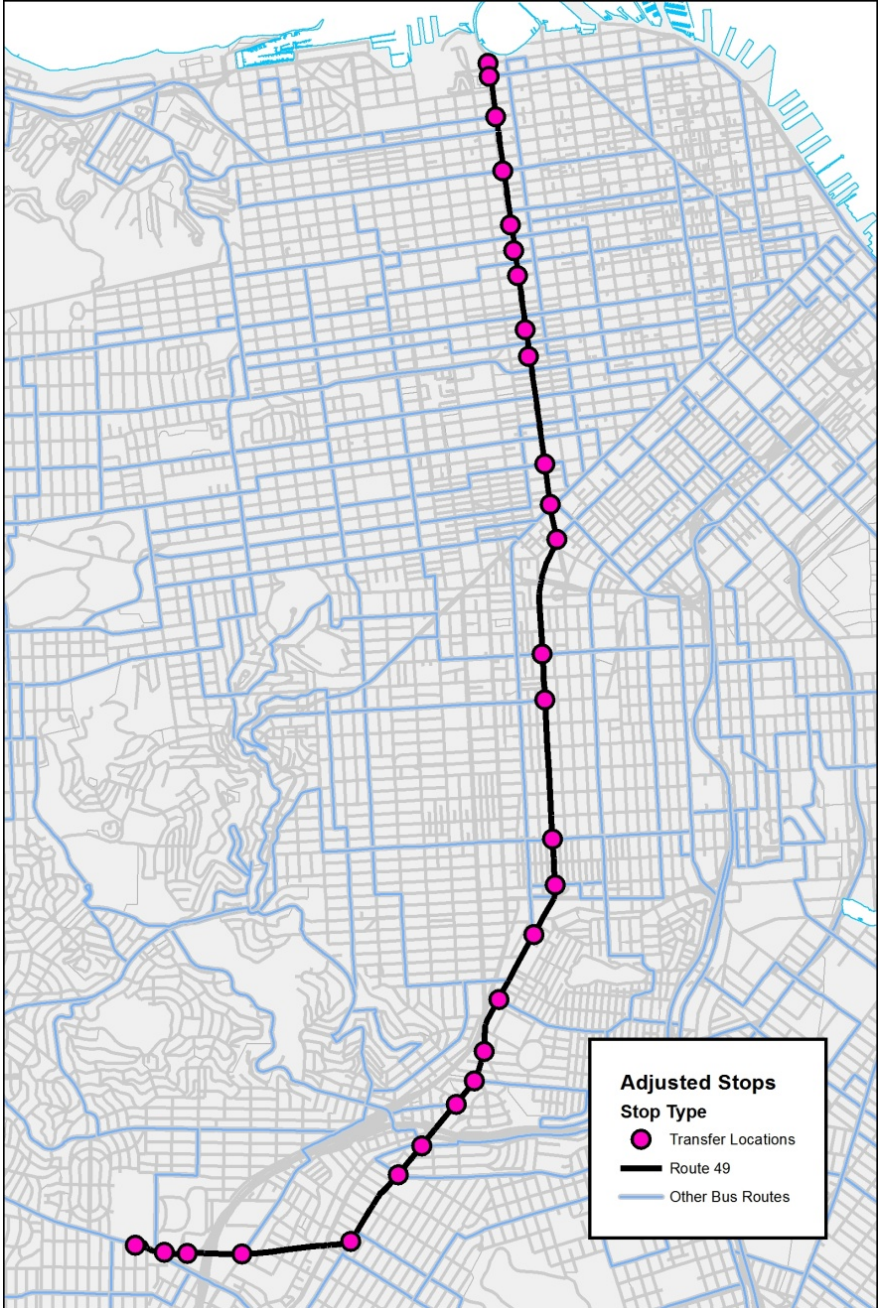


### 7.3 Analysis of Accessibility to SFMTA Route 49

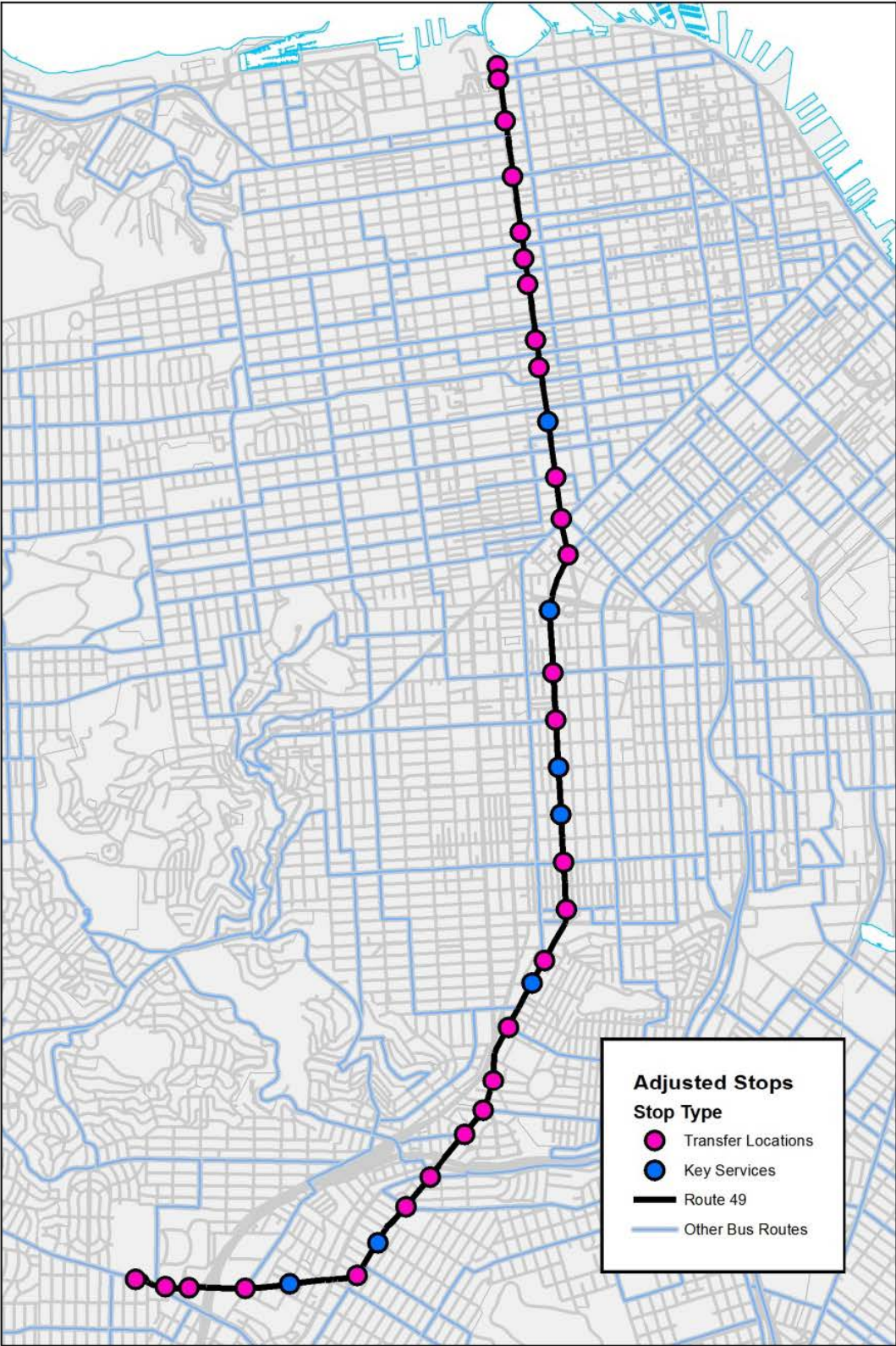
#### 7.3.1 Key Stop Placement Steps

Similar to previous applications of the procedure, major stops were identified in terms of transfer opportunities (Figure 7-6), service and activity centers (Figure 7-7), steep grade segments (Figure 7-8) and target separation between stops (Figure 7-9).

Figure 7-6: Potential Transfer Points along SFMTA Route 49



**Figure 7-7: Key Service and Facility Locations along SFMTA Route 49**



**Figure 7-8: Placement of Stops in Steep Grade Segments along SFMTA Route 49**

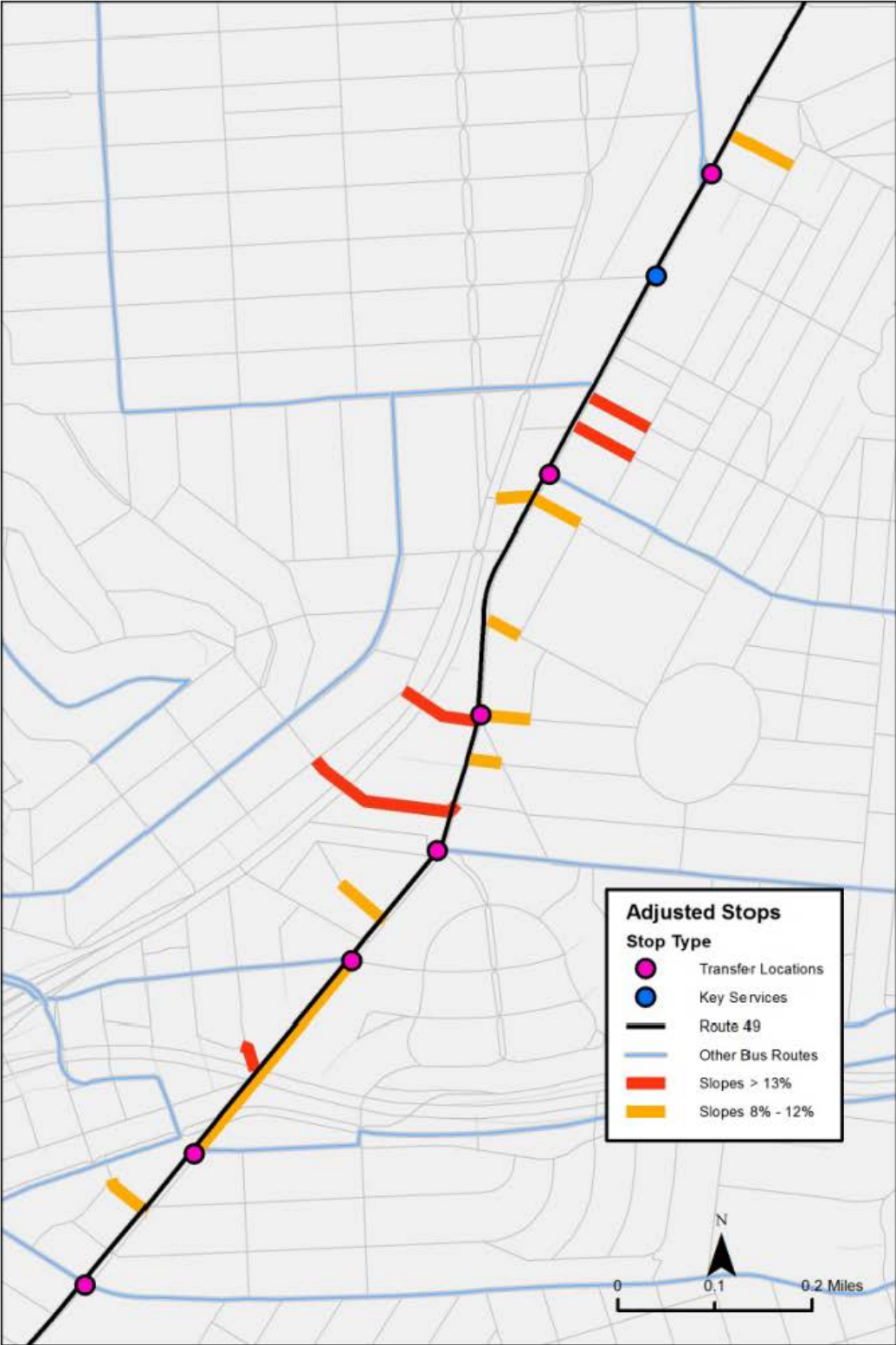
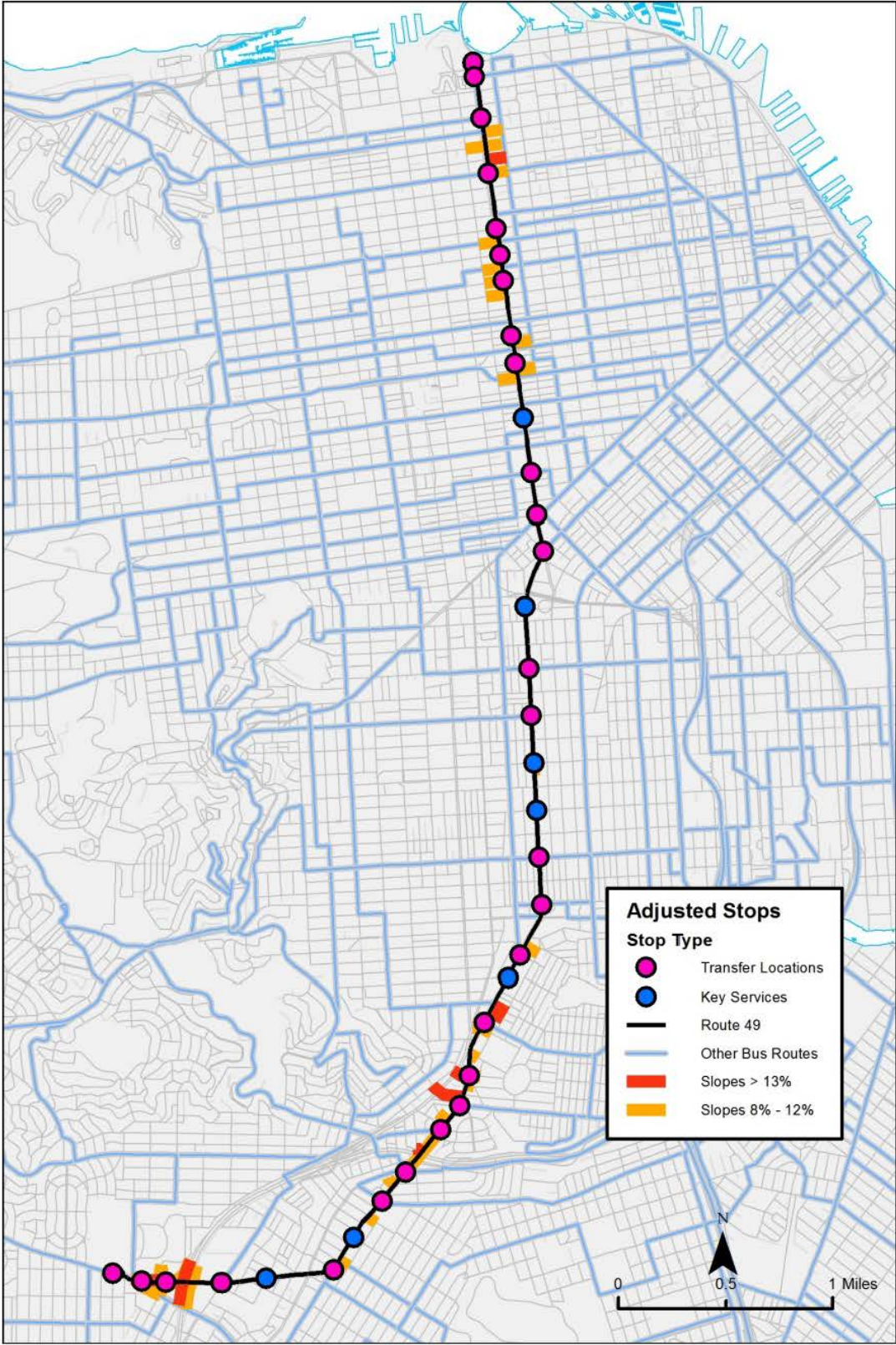


Figure 7-9: Complete Placement of Stops along SFMTA Route 71



### **7.3.2 Buffer Analysis**

SFMTA Route 49 had 53 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.125-mile buffer distances (0.25-mile diameter), is 1.64 square miles of which 0.84 square mile of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 51 percent overlap in catchment areas of stop locations. Figures 7-10 show buffer overlaps under existing conditions in different segments of the route.

Applying the procedure of this study would result in 35 stop locations with a total coverage area of 1.48 square miles, which is approximately a 10 percent reduction compared to the existing stops. Of that coverage area, 0.24 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 16 percent or approximately 30 percent of the existing condition. Figures 7-10 also show buffer overlaps under adjusted conditions for various segments of the route.

Figures 7-10a and 7-10b show zoomed-in views of sections of SFMTA Route 49 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 7-11a and 7-11b show the same comparative overlap information superimposed over a base map of activity concentrations along the corridor.

Figure 7-10a: Comparative Buffer Overlaps along SFMTA Route 49 (1 of 2)

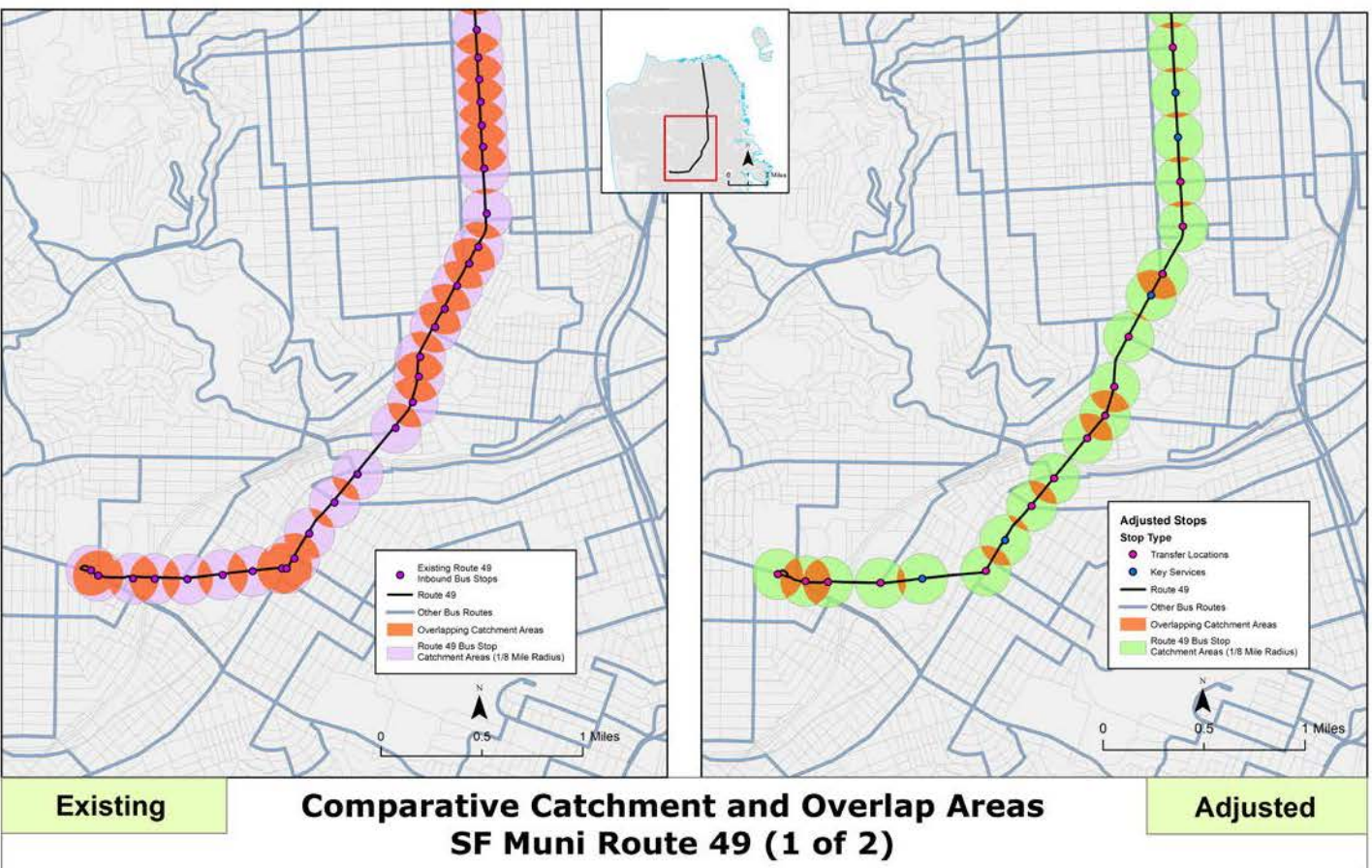




Figure 7-10b: Comparative Buffer Overlaps along SFMTA Route 49 (2 of 2)

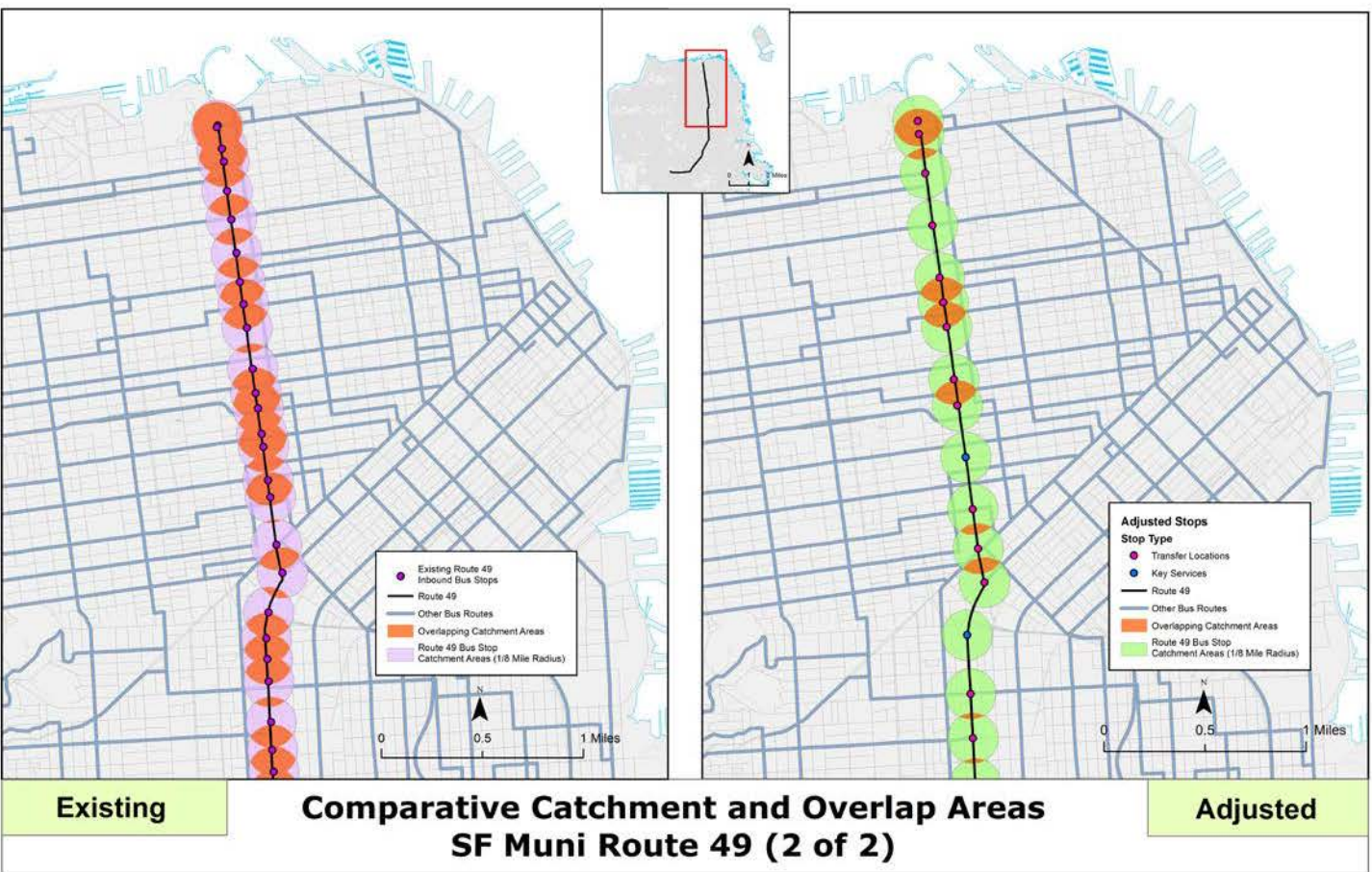


Figure 7-11a: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 49 (1 of 2)

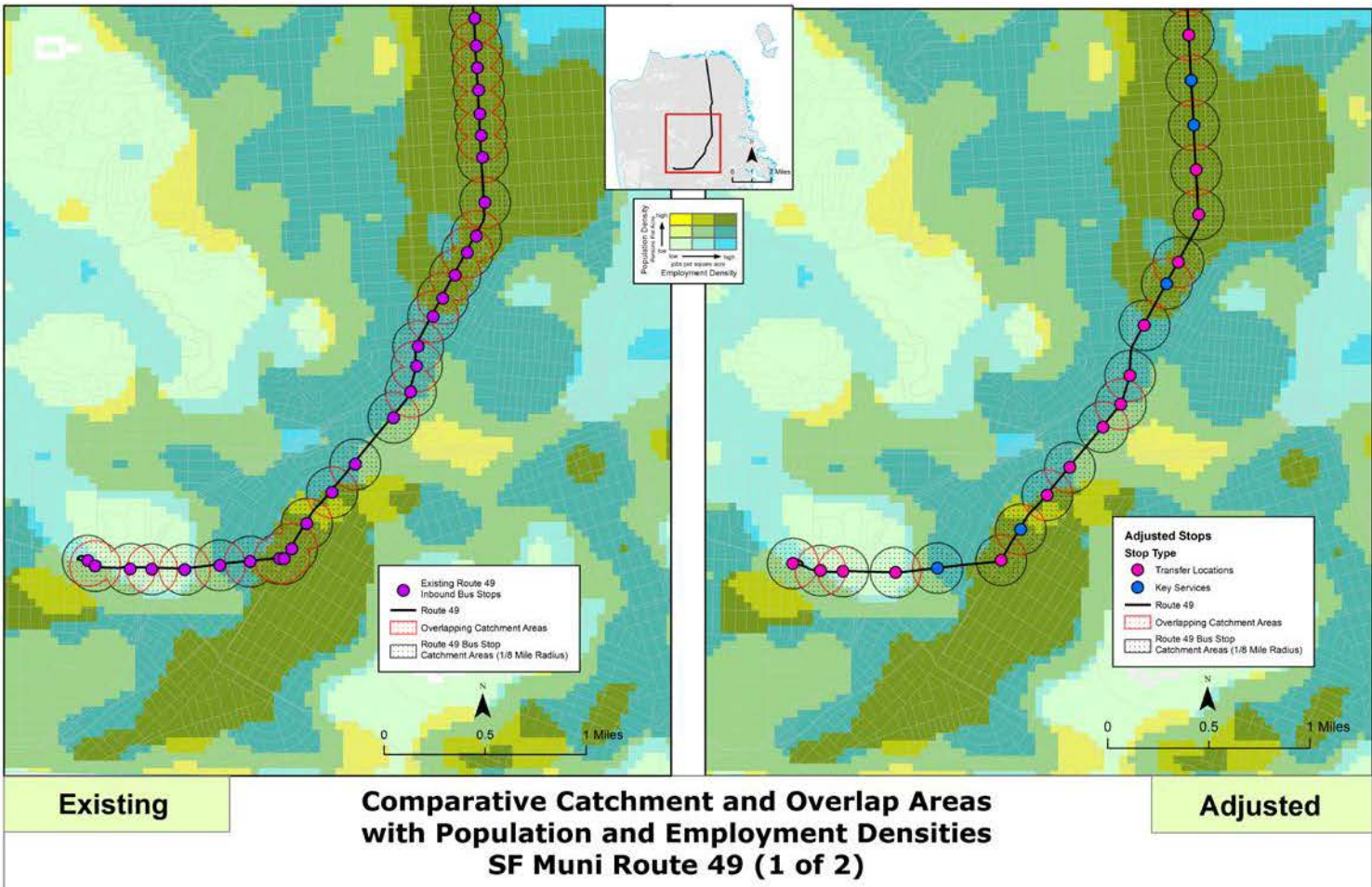
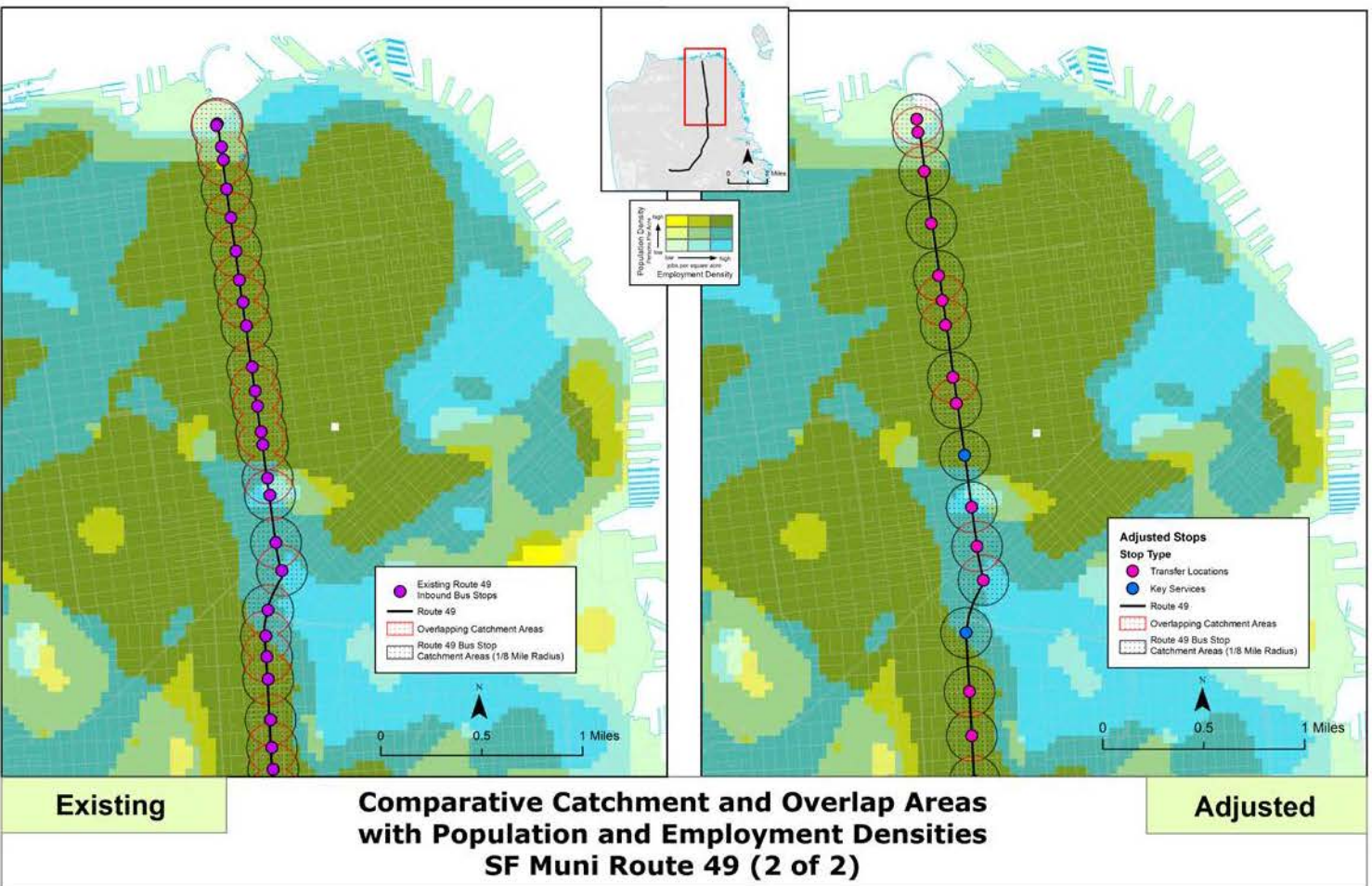


Figure 7-11a: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 49 (2 of 2)



## 7.4 Analysis of Accessibility to SFMTA Route 71

### 7.4.1 Key Stop Placement Steps

Similar to previous applications of the procedure, major stops were identified in terms of transfer opportunities (Figure 7-12), service and activity centers (Figure 7-13), steep grade segments (Figure 7-14) and target separation between stops (Figure 7-15).

Figure 7-12: Potential Transfer Points along SFMTA Route 71

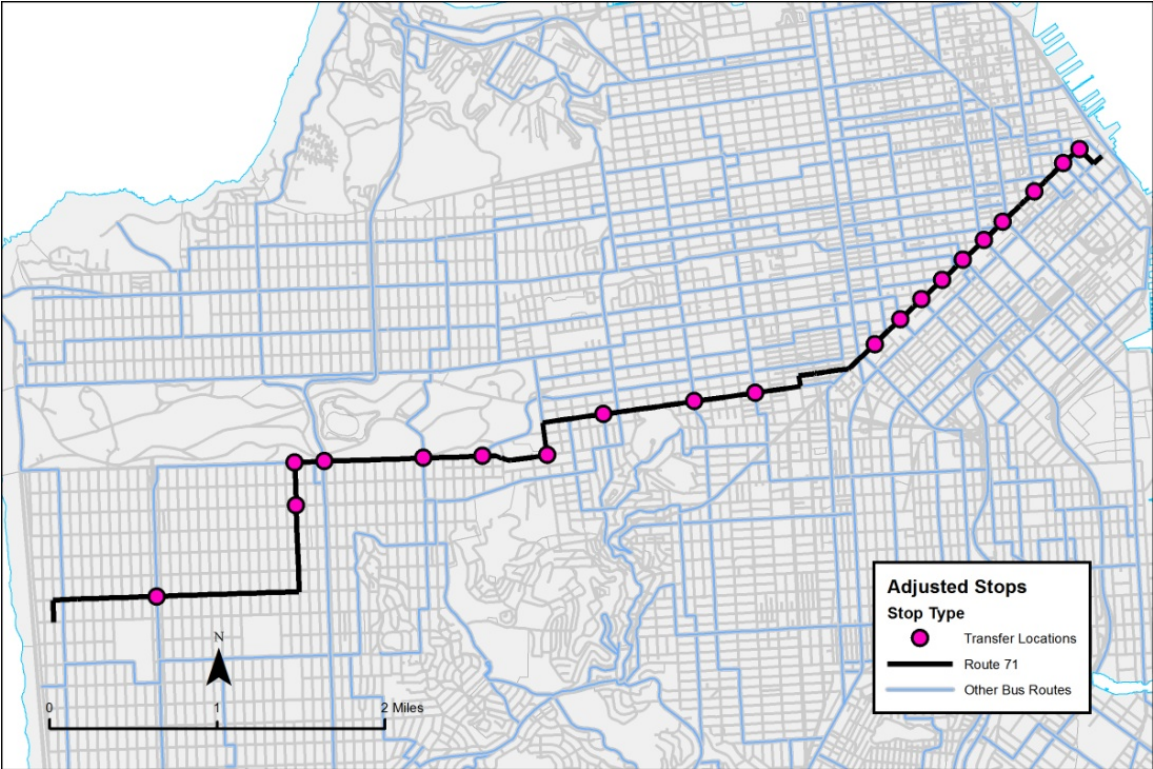


Figure 7-13: Key Service and Facility Locations along SFMTA Route 71

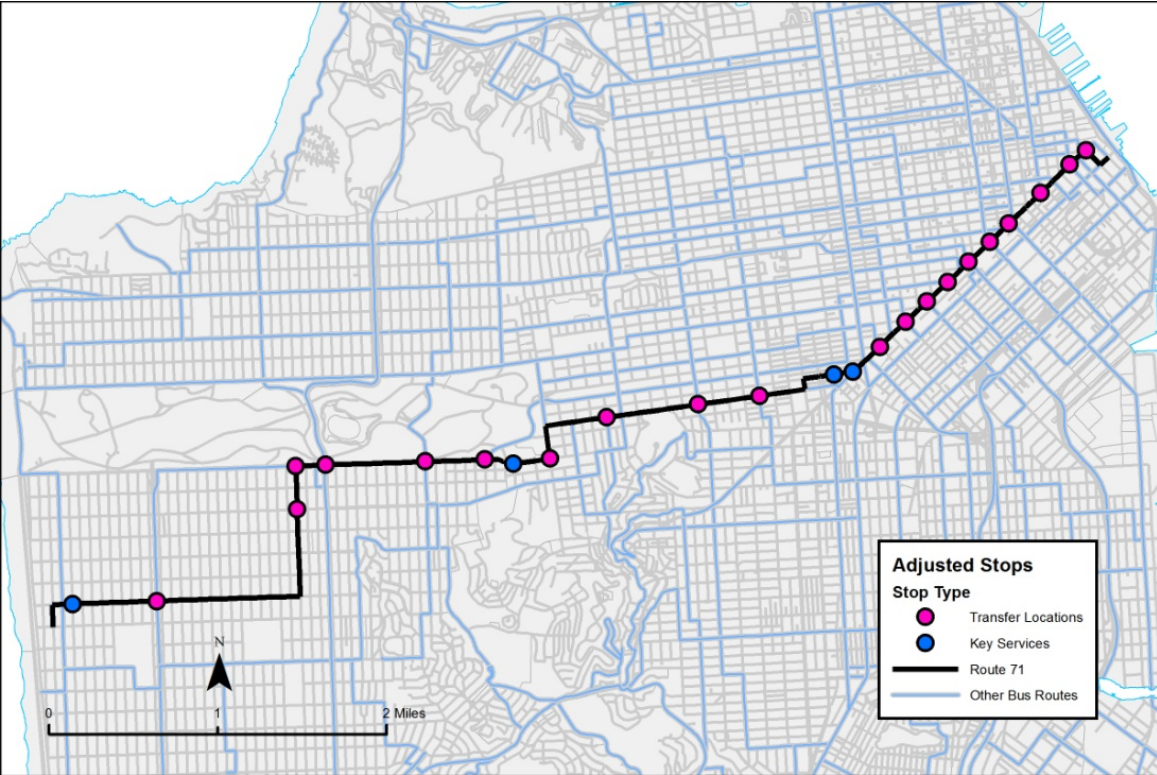
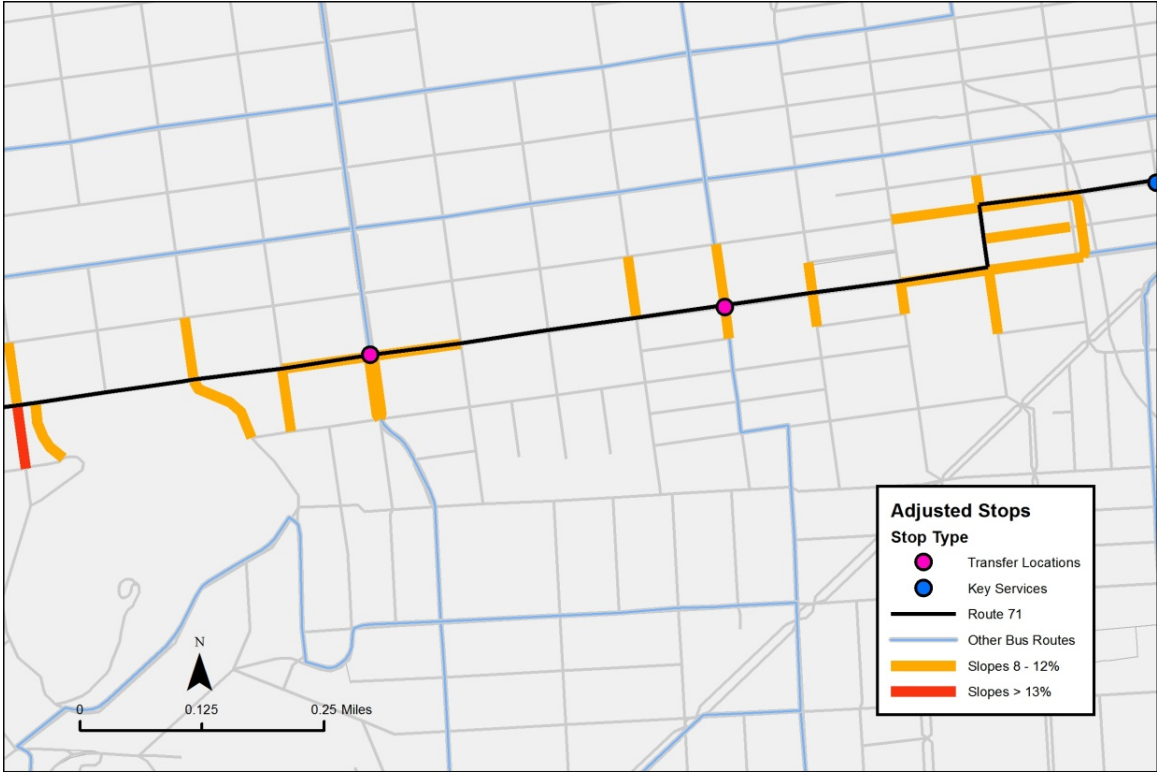
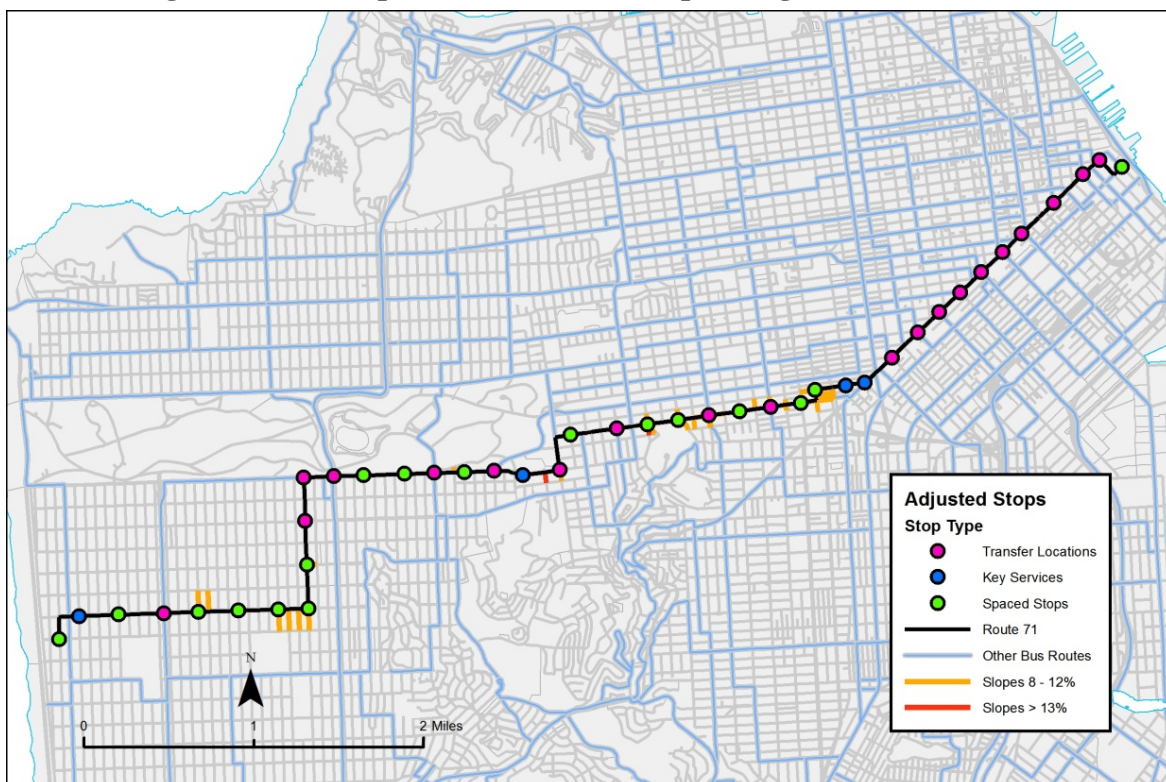


Figure 7-14: Placement of Stops in Steep Grade Segments along SFMTA Route 71



**Figure 7-15: Complete Placement of Stops along SFMTA Route 71**



### 7.4.2 Buffer Analysis

SFMTA Route 71 had 61 existing stops. The analysis of buffer overlap indicates the total area of coverage, assuming 0.125-mile buffer distances (0.25-mile diameter), is 1.89 square miles of which 0.95 square mile of that coverage area is overlapped by the catchment of two or more bus stops. This equates to a 50 percent overlap in catchment areas of stop locations. Figures 7-16 show buffer overlaps under existing conditions in different segments of the route.

Applying the procedure of this study would result in 41 stop locations with a total coverage area of 1.73 square miles, which is nearly the same as for the existing stops. Of that coverage area, 0.27 square miles is covered by two or more bus stops. This reduces the total percentage of overlapping coverage area to 16 percent or approximately one third of the existing condition. Figures 7-16 also show buffer overlaps under adjusted conditions for various segments of the route.

Figures 7-17a through 7-17c show zoomed-in views of sections of SFMTA Route 71 for side-by-side comparisons of buffer overlaps between existing and adjusted conditions. Figures 7-18a through 7-18c show the same comparative overlap information superimposed over a base map of activity concentrations along the corridor.

Figure 7-16a: Comparative Buffer Overlaps along SFMTA Route 71 (1 of 3)

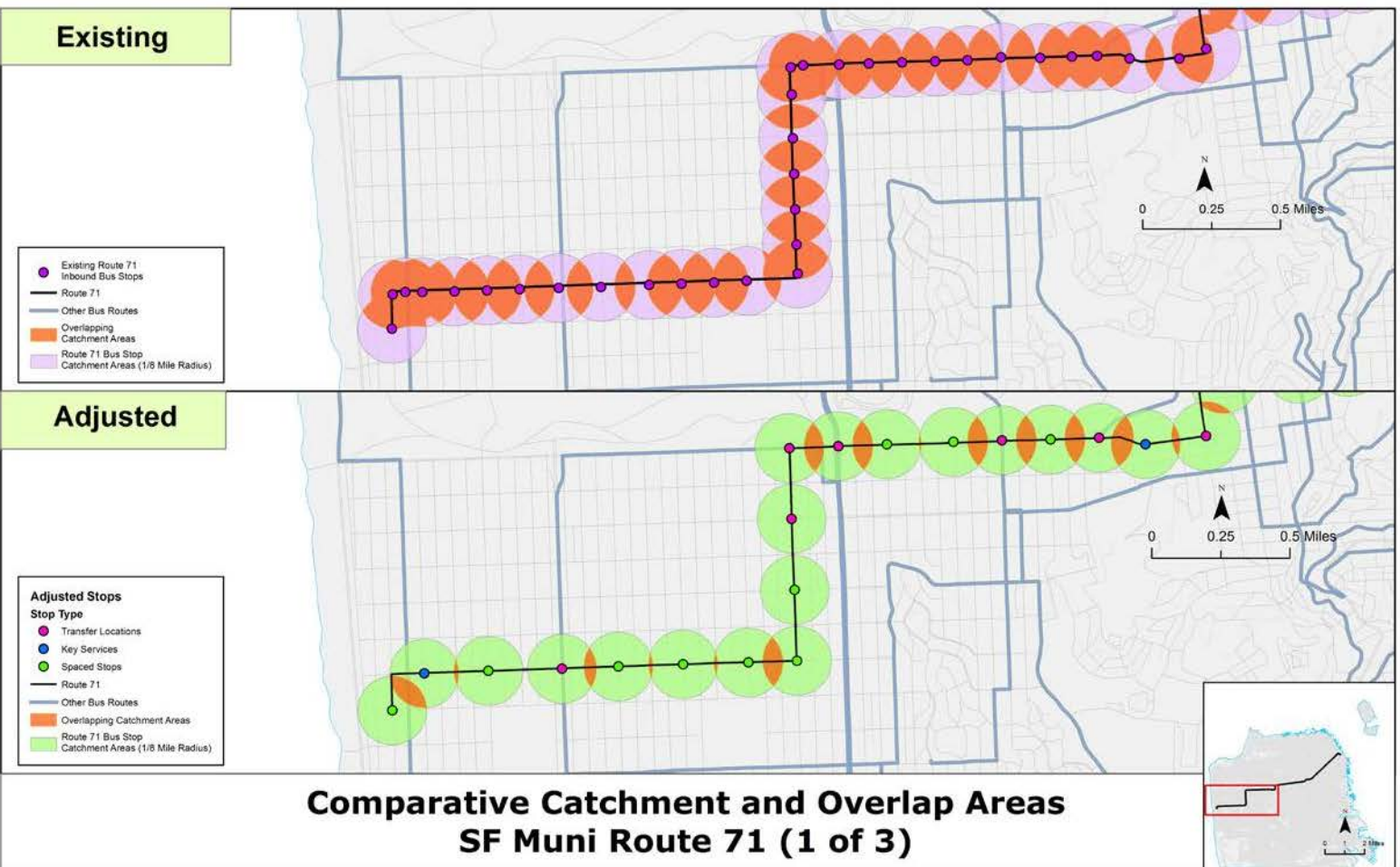


Figure 7-16b: Comparative Buffer Overlaps along SFMTA Route 71 (2 of 3)

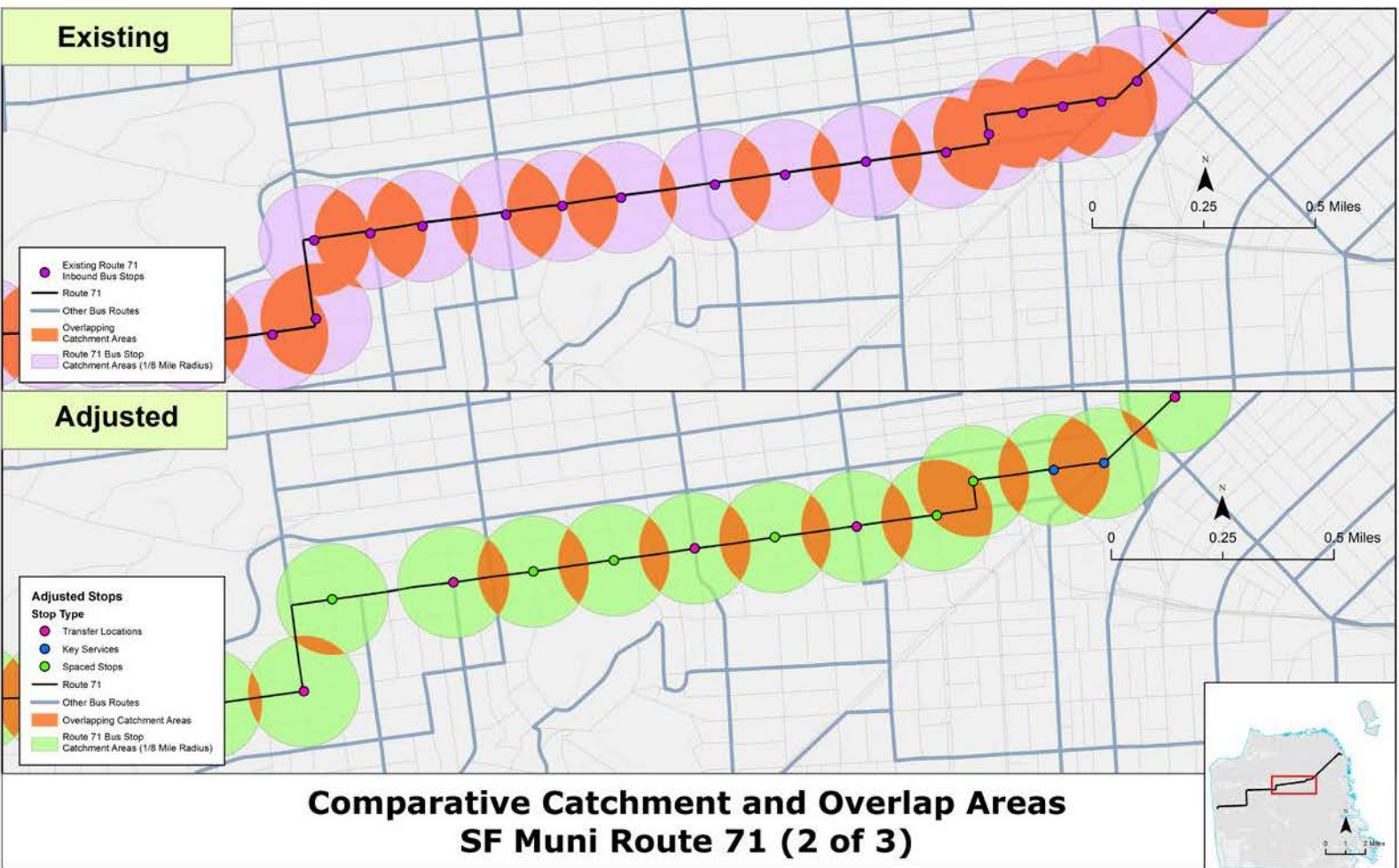




Figure 7-16c: Comparative Buffer Overlaps along SFMTA Route 71 (3 of 3)



Figure 7-17a: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 71 (1 of 3)

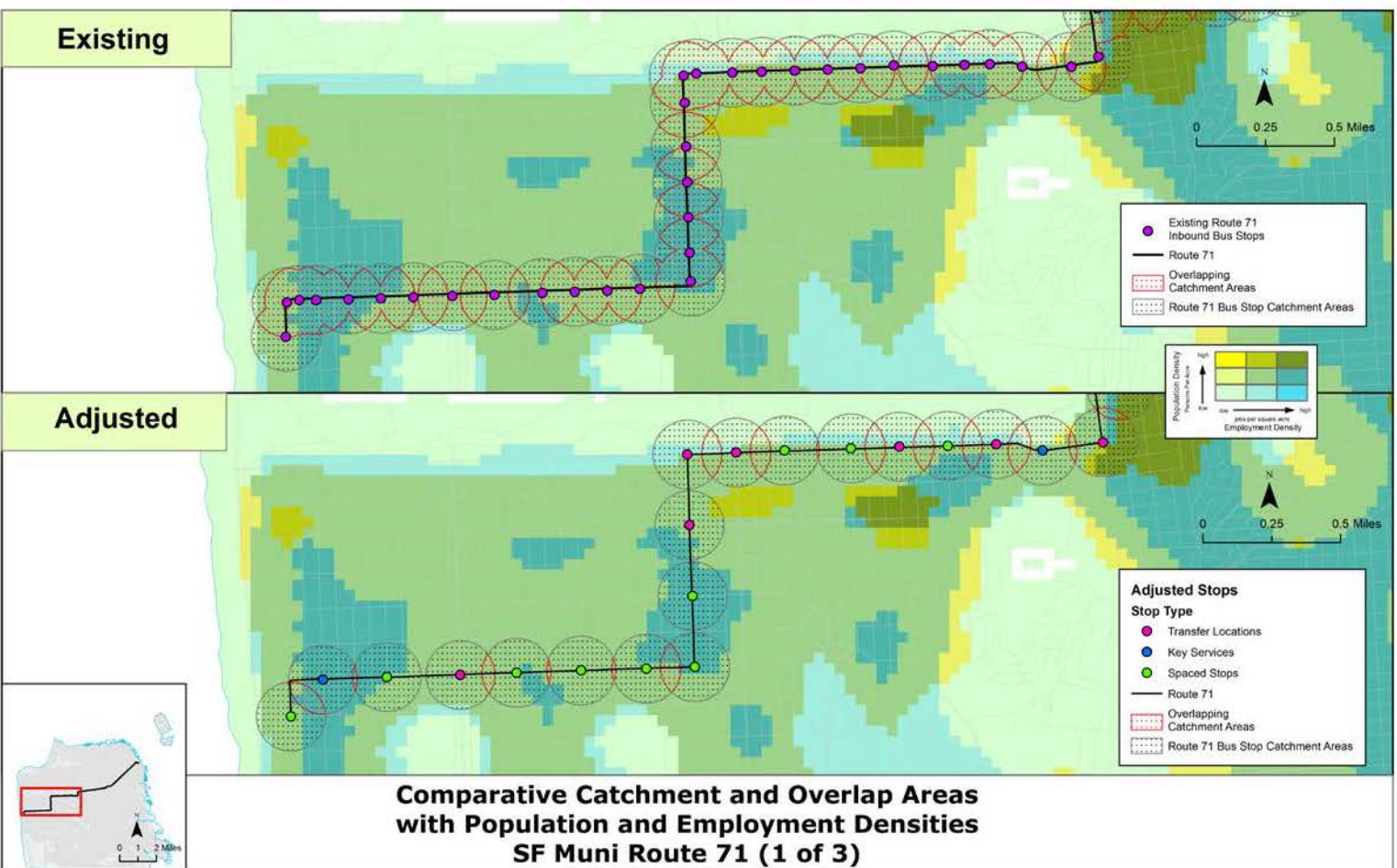


Figure 7-17b: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 71 (2 of 3)

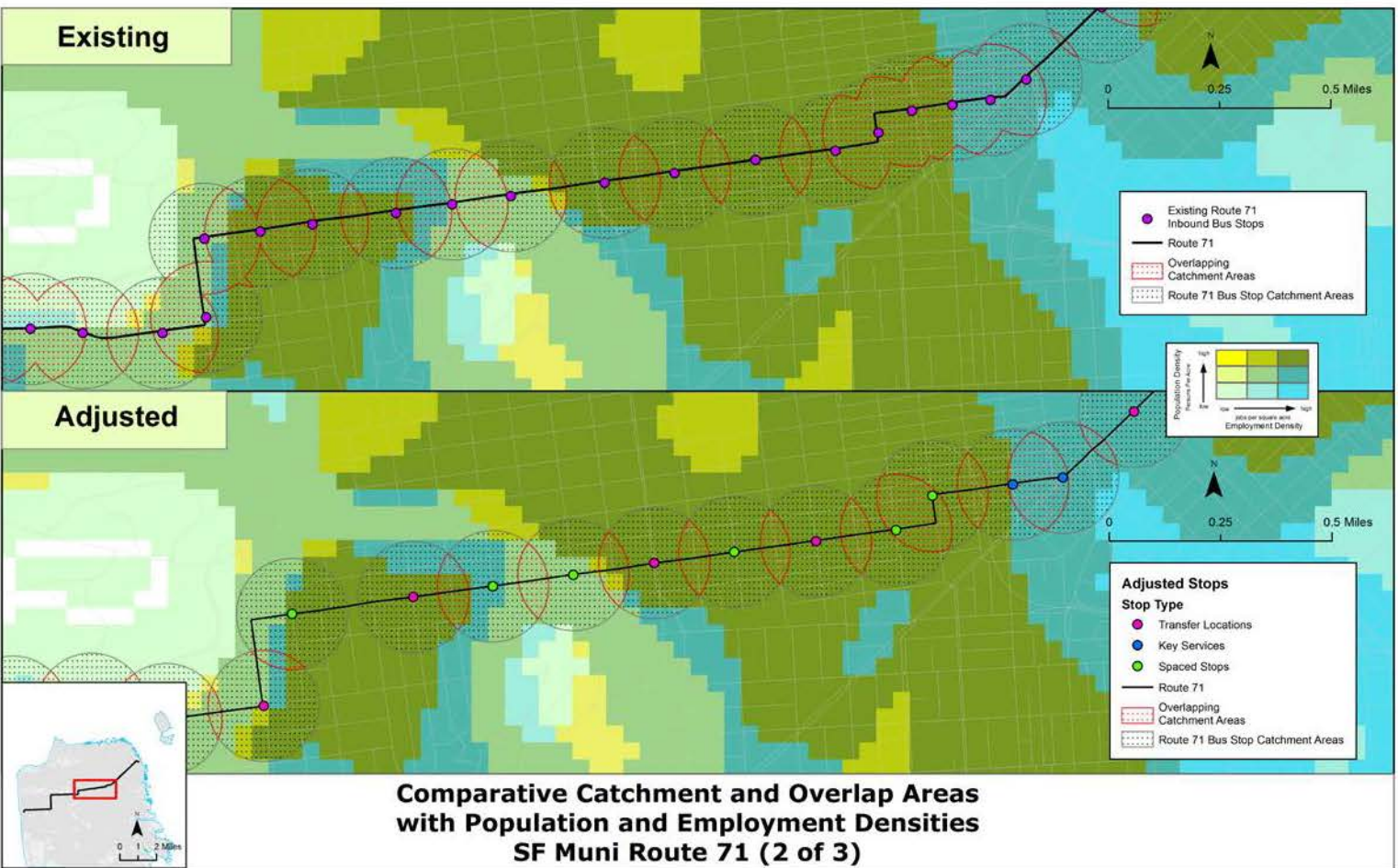
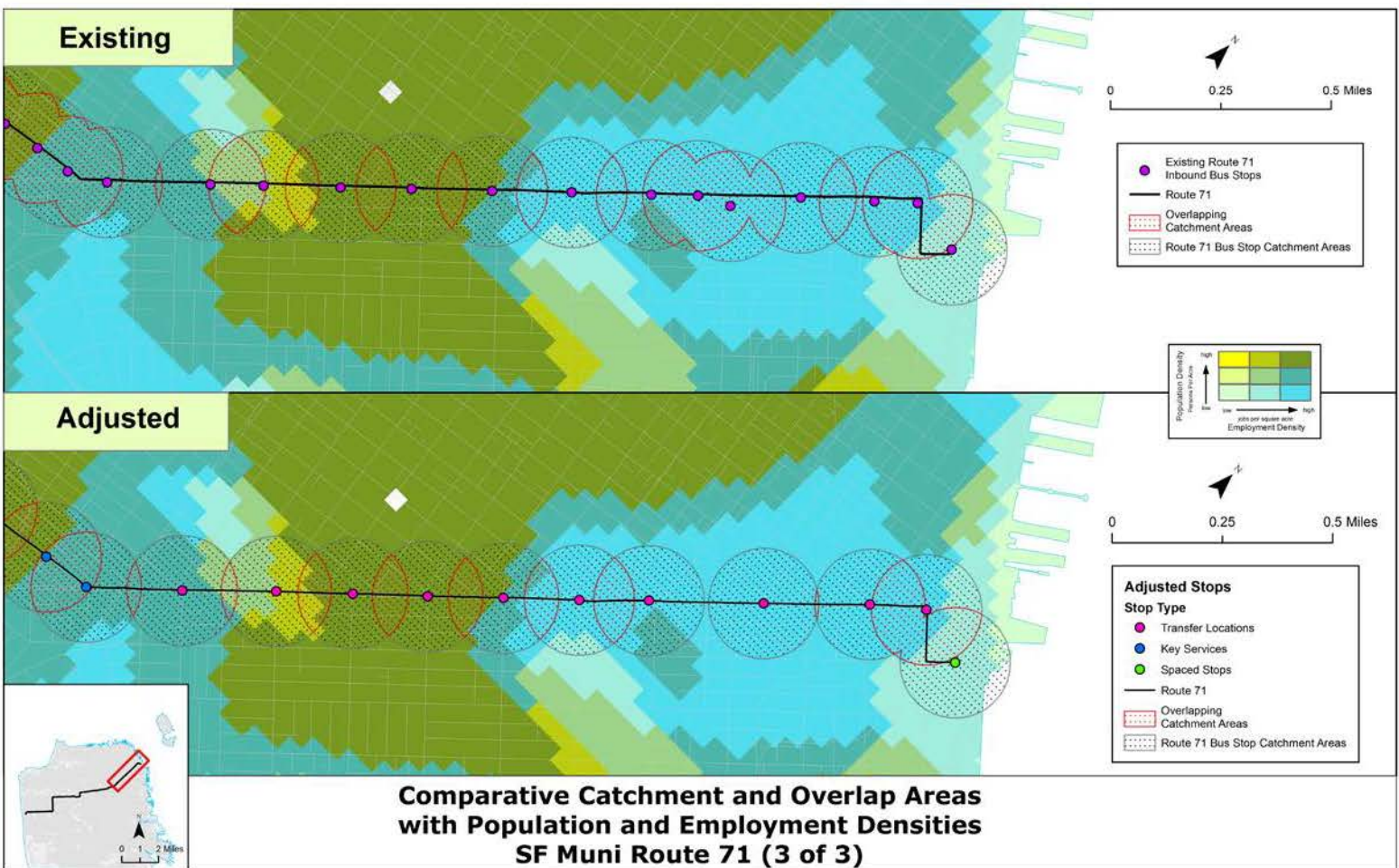


Figure 7-17c: Comparative Buffer Overlaps vs. Activity Centers: SFMTA Route 71 (3 of 3)

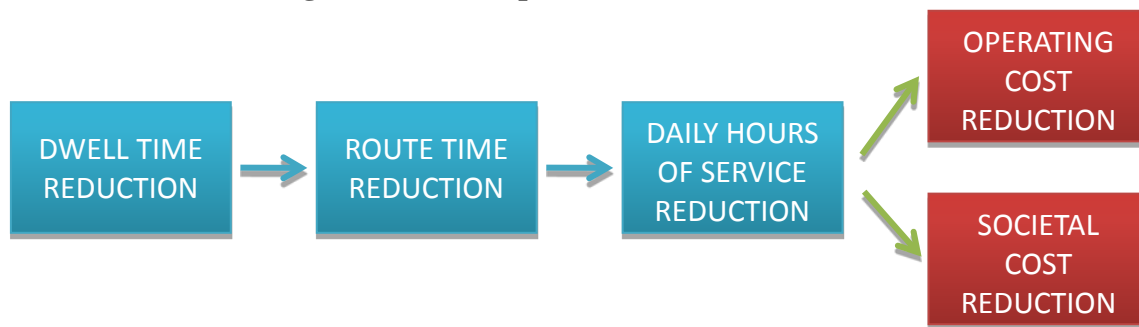


## 8.0 Potential Savings

### 8.1 Quick Response Benefit Calculations

This section includes quick estimates of the potential benefits of the applications of the procedures of this study for stop spacing along the case study routes. These are termed quick response calculations because they apply parameters from other studies reported in the literature to provide generalized ideas of orders of magnitude in potential benefits. Figure 8-1 illustrates the benefits estimation procedure. The number of stop eliminations reported for the individual case study routes serve as inputs to the benefits estimation process. Stop eliminations are used to estimate dwell time reductions, which are in turn used to estimate route time reductions. The latter are expanded over the day and year to estimate operating cost reductions as well as general societal cost reductions.

**Figure 8-1: A Simplified Benefits Estimation Process**



### 8.2 Summary of Stop Eliminations

Table 8-1 summarizes the number of stops proposed to be eliminated following the application of the procedure of this study. Consistent with the literature, the case study routes have too many superfluous stops that do not increase user accessibility. The more dense the environment the more superfluous stops were identified for relocation or consolidation.

**Table 8-1: Stop Eliminations with Proposed Procedure**

Case Study Route	Type of Environment	Number of Stops			
		Existing	Adjusted	Reduction	Percent Reduction
SLO Transit Route 4	small urban	34	19	15	44%
RTA Route 9	suburban/rural	30	27	3	10%
RTA Route 10	suburban/rural	25	17	8	32%
SFMTA Route 2	large urban	52	31	21	40%
SFMTA Route 49	large urban	53	35	18	34%
SFMTA Route 71	large urban	61	41	20	33%

### 8.3 Potential Dwell Time Reductions

Figure 8-2 shows the ranges of percent reductions in one-way route travel times that are possible depending on time of day and traffic conditions. The estimates apply the ranges of dwell time reductions reported in the literature of 15 seconds to 40 seconds per stop. For instance, Furth and Rahbee (2000) estimated that the deceleration, dwell and acceleration at each stop took 17 seconds. Consistent with the recommended number of stops to eliminate from this study’s procedure the more dense urban areas could potentially realize much higher proportional route time savings of 10 percent to 30 percent.

Table 8-2: Estimated Ranges of Dwell Time Reductions

Case Study Route	Existing One-Way Route Time (minutes)	Number of Stop Reductions	Dwell Time Reductions as Percent of Route Travel Time		
			Low @ 15 sec./stop	Medium @ 20 sec./stop	High @ 40 sec./stop
SLO Transit Route 4	55	15	7%	9%	18%
RTA Route 9	70	3	1%	1%	3%
RTA Route 10	86	8	2%	3%	6%
SFMTA Route 2	44	21	12%	16%	32%
SFMTA Route 49	60	18	8%	10%	20%
SFMTA Route 71	55	20	9%	12%	24%

### 8.4 Estimated Cost Reductions

#### 8.4.1 Operating and Societal

Estimates of time savings per run (or trip) from the elimination of stops were expanded to daily hours of savings over the number of runs scheduled for a day. These daily time savings were further expanded to annual time savings assuming 260 days of operation in the year. Then default values of unit costs reported in the literature were applied to time savings to estimate cost savings. The unit costs were adopted for operating costs (at \$80 per hour) and total societal costs (at \$132 per hour) from Furth and Rahbee (2000). Total societal costs represent values of time for operating, riding, and walking.

Results indicate the potential for substantial daily savings. This is especially notable for the routes in the dense urban environments. Even the least affected route is estimated to save at least \$4,000 per year while the most affected route could save more than \$180,000 per year in operating costs.

Table 8-3: Estimates of Potential Cost Reductions

Case Study Route	Daily Values		Operating Cost Savings (\$)		Societal Cost Savings (\$)	
	Trips Made	Hours Saved	Daily	Yearly	Daily	Yearly
<b>@ 15-second reduction per stop</b>						
SLO Transit Route 4	28	1.8	140	36,400	231	60,060
RTA Route 9	16	0.2	16	4,160	26	6,864
RTA Route 10	13	0.4	35	9,013	57	14,872
SFMTA Route 2	59	5.2	413	107,380	681	177,177
SFMTA Route 49	118	8.9	708	184,080	1,168	303,732
SFMTA Route 71	74	6.2	493	128,267	814	211,640
<b>@ 40-second reduction per stop</b>						
SLO Transit Route 4	28	4.7	373	97,067	616	160,160
RTA Route 9	16	0.5	43	11,093	70	18,304
RTA Route 10	13	1.2	92	24,036	153	39,659
SFMTA Route 2	59	13.8	1,101	286,347	1,817	472,472
SFMTA Route 49	118	23.6	1,888	490,880	3,115	809,952
SFMTA Route 71	74	16.4	1,316	342,044	2,171	564,373

**Assumptions:**

- a. Days of operation per year = 260 days
- b. Operating Cost per Hour = \$80
- c. Societal Cost per Hour = \$132 (includes values of time for operating, riding, and walking)

**8.4.2 Fuel and Oil**

Reductions in dwell times over a route translate into increases in speed of travel over the route. Such increases in travel speeds have direct implications for fuel and oil consumption, which were captured together with labor costs in the estimates of operating costs presented in the previous subsection. Using values reported in the literature, one can estimate potential savings in the costs of fuel and oil associated with the application of the stop spacing procedure proposed in this study. For example, at very low speeds, for every 5mph speed increase, 50 fewer gallons of fuel are consumed per 1,000 miles (TTI, 1990). Figure 2-2 through 2-4 in the

literature review section show relationships between stop spacing and fuel or oil consumption. Applying similar values to the stop spacing adjustments could result in the savings shown in Table 8-4. At today’s high fuel prices, these savings could add up to substantial savings in operating costs. At \$4 per gallon, annual fuel cost savings per route could range between \$1,500 and \$16,000. Similarly, at \$2.5 per quart, annual cost savings in motor oil per route could range between \$175 and \$2,000.

Table 8-4: Estimates of Potential Savings in Fuel and Oil

Case Study Route	Route Length (miles)	One-Way Route Time (minutes)		Operating Speeds (mph)		Annual Savings	
		Existing	Adjusted	Existing	Adjusted	Fuel (gallons)	Oil (quarts)
<b>@ 15-second reduction per stop</b>							
SLO Transit Route 4	13.3	55.0	51	14.5	15.6	1,028	206
RTA Route 9	30	70.0	69	25.7	26.0	348	70
RTA Route 10	34.4	86.0	84	24.0	24.6	664	133
SFMTA Route 2	4.8	44.0	39	6.5	7.4	653	131
SFMTA Route 49	6.9	60.0	56	6.9	7.5	1,184	237
SFMTA Route 71	7.7	55.0	50	8.4	9.2	1,244	249
<b>@ 40-second reduction per stop</b>							
SLO Transit Route 4	13.3	55	45	15	18	3,122	624
RTA Route 9	30	70	68	26	26	944	189
RTA Route 10	34.4	86	81	24	26	1,845	369
SFMTA Route 2	4.8	44	30	7	10	2,249	450
SFMTA Route 49	6.9	60	48	7	9	3,652	730
SFMTA Route 71	7.7	55	42	8	11	3,982	796

**Assumptions:**

- a. On flat terrain, every 5mph speed increase would results in 50 fewer gallons of fuel consumption per 1,000 miles (TTI, 1990)
- b. On flat terrain, every 5mph speed increase would results in 10 fewer quarts of oil consumption per 1,000 miles (TTI, 1990)
- c. Days of operation per year = 260 days



### 8.5 Effect on Accessibility

Similar to the findings on the MBTA study by Furth and Rahbee (2000), the application of this study procedure to the case study routes resulted in the following: (a) 10 percent to 44 percent reduction in the number of stops; and (b) 9 percentage point to 44 percentage point reduction in buffer overlaps; but (c) less than commensurate reduction in coverage area of 0 percent to 13 percent, which would affect only those on the fringes of the catchment areas of stops; and yet (d) potential reductions in route travel time for all patrons ranging from 1 percent to 12 percent for the low estimate and 3 percent to 32 percent for the high estimate. Table 8-5 shows a summary. These results provide additional confirmation of the potential benefits of properly defined stop spacing.

Table 8-5: Summary Effects of Stop Spacing on Accessibility

Case Study Route	Areal Coverage (square miles)			Buffer Overlap (square miles)		Buffer as Percent of Coverage Overlap		Percent Reduction in Route Time	
	Existing	Adjusted	Percent Coverage Reduction	Existing	Adjusted	Existing	Adjusted	Low	High
SLO Transit Route 4	4.29	3.75	13%	1.95	0.89	45	23	7%	18%
RTA Route 9	4.7	4.7	0%	1	0.57	21	12	1%	3%
RTA Route 10	2.97	3.09	-4%	0.65	0.28	22	9	2%	6%
SFMTA Route 2	1.5	1.34	11%	0.84	0.16	56	12	12%	32%
SFMTA Route 49	1.64	1.48	10%	0.84	0.24	51	16	8%	20%
SFMTA Route 71	1.89	1.73	8%	0.95	0.27	50	16	9%	24%

## **9.0 Conclusions and Recommendations**

### **9.1 Concluding Observations**

This study has provided additional confirmation of the potential benefits of properly defined stop spacing. The study applied knowledge from previous research to develop a simple tool for practical application by practitioners to realize the benefits of proper stop spacing whether in enhancing operations or in planning for future expansion.

It is an obvious notion that the more people who live or engage in other human activities close to transit stops, the more accessible the service would be to them and the higher the potential of using it. Many transit operators established several stops to realize this notion. However, for a given traffic and roadway condition, the more frequent stops are along a route the slower the route travel time due to deceleration, stopping and acceleration. So also the farther stops are from each other, the longer the average distances for access and egress. Early research revealed that the optimal spacing therefore is one that minimizes total travel time, which includes access and in-vehicle times.

Further research has shown that there are operating cost increases associated with close spacing and operating cost savings associated with wide spacing. The optimal spacing therefore is one that minimizes total costs, which include travel time costs to transit users and operating costs to transit providers. Such an achievement would both improve operational efficiency and maintain good accessibility. Accessibility can be dealt with by guaranteeing that population concentrations are within acceptable walking distances to transit, which the literature places at a quarter to a half mile. Other provisions can also improve accessibility by accommodating those who would access the service by other modes. Some examples are bicycle parking for bicyclists, convenience of transfer for users of other transit service, and parking or drop-off locations for automobiles. If too large and not in a structure, automobile parking can occupy so much space as to extend the access distance for walkers and bicyclists. The preferred policy would be to concentrate activities and locate stops in such a way as to prioritize walk access

Research revealed that stop spacing is generally shorter in the US than other countries abroad, but transit use is higher in those places. In general, European cities recommend 3 to 4 stops per mile, or approximately 1300 feet of separation. American guidelines recommend stops between approximately 500 to 1300 feet of separation. While increasing stop spacing distances could increase walking distances for some users, in places with high transit stop density, most access distances will remain within the acceptability threshold of a five- to ten-minute walk. This study added confirmation to this observation. Studies have also shown that fewer stops will concentrate passengers at the remaining stops along the route, which can

increase predictability, allow for a more accurate schedule, and result in a more reliable service. Concentrating passengers can also reduce the dwell time per passenger per stop, which leads to an overall reduction in route travel time. Reducing travel time reduces operating expenses which in turn could enable operators to provide more stop amenities. Reduced operating expenses may also translate into more frequent service. Ultimately, a more reliable service means passengers will spend less time waiting at bus stops.

This study has similarities with previous studies. It uses GIS data by census block but with uses population and employment data rather than ridership to represent the spatial distribution of potential demand. This distribution is used to determine both the efficiency in the alignment of routes and the preferred locations of stops. Thus it can serve as a tool in planning for existing settlements as well as future settlements when ridership data is not available. It is also similar to other studies that recognize the importance of accessibility to transit and the implications of cost for both riders and operators. It differs by not using mathematical programming, but is similar to simulation in the approach of using multiple criteria in a step-by-step approach to determining stop locations.

The procedure for stop spacing used in this study considers the factors most important to safeguard accessibility while enhancing performance. In a rough order of priority, the factors are: locations of the highest concentrations of population and employment; transfer points; major service centers; and steep grade segments. Then a combination of adopted stop spacing and acceptable walking distance is used to fill in, eliminate or relocate other stops.

The appeal of this procedure lies in its simplicity. Input to the process is readily available. Block level data is obtainable by fine geographical area for population and employment from the US census. Instead of reliance on the decennial census, most recent data is available because of the American Community Survey and the data is easy to obtain from the Census LEHD online mapping application. Although it does not involve specific linear programming formulation, the procedure still encapsulates factors of user convenience and time costs as well as operator costs. These were termed in the literature operating and societal costs.

The application of this study procedure to the case study routes produced results that are consistent with findings in the literature. Key results of its application to the specific case study routes may be outlined as follows:

- e. Reduction in the number of stops by 10 percent to 44 percent;
- f. Reduction in buffer overlaps by 9 percentage points to 44 percentage points;
- g. Less than commensurate reduction in coverage area of 0 percent to 13 percent, which would mostly affect those on the fringes of the catchment areas of stops;

- h. Potential reductions in route travel time for all patrons ranging from 1 percent to 12 percent for the low estimate and from 3 percent to 32 percent for the high estimate.

## **9.2 Recommendations**

Besides recommending widespread adoption of this methodology for routine application by transit planners and operators, a few specifics are pointed out as part of the adoption process. These are presented in four theme areas: spatial analysis framework; stop spacing distances; the step-by-step stop spacing procedure; and public input.

### **9.2.1 Spatial Analysis**

The geographical detail of spatial analysis is important in stop spacing. The literature postulates that estimates of public transit coverage based on census blocks have proven to be the most disaggregate and the most representative of the population served. The availability of census population and employment data at the block level facilitates spatial analysis with GIS at a detailed geographic scale rather than the macro level of the traditional travel analysis zones. The data also provide alternatives to estimates of ridership. Planners are well-served to conduct analysis at the census block level for which data is readily available.

Where tools permit, network distances (rather than Euclidean distances) should be used to demarcate catchment or coverage areas of stops. The availability of robust GIS software facilitates this type of spatial analysis.

### **9.2.2 Stop Spacing Standards**

There is general recognition that people are willing to walk ¼-mile to access human activities. If two adjacent stops have ¼-mile catchment areas, then the separation between them is two adjacent radii or ½-mile (2640 feet). This distance defines the upper limit of separation in adopted guidelines of operators for suburban environments. Use a half-mile separation as the target distance in built-up portions of small urban and suburban or rural areas.

There is the general tendency for most study results to prescribe shorter distances for dense urban areas than for more sparsely developed areas. Simulation results and guidelines from abroad all seem to point to approximately four stops per mile or ¼-mile separation (1320 feet) which would result in a non-overlapped catchment area radius of 1/8-mile per station. Use a quarter-mile separation as the target distance for densely built portions of large urbanized areas.

Vary these two target distances under two circumstances: (a) for “express” or “rapid” service, use two times the prevailing separation or ½-mile to a mile; (b) for steep segments of 10 percent grade or more use half the prevailing separation.

### 9.2.3 Stop Spacing Procedure

The adopted stop spacing procedure should include consideration for multiple factors, such as proximity to concentrations of human activities, ready access to services, potential for transfers, topography and density of urban development. The latter dictates the target separation distance. The process in a nutshell is outlined as follows:

11. Identify population concentrations by census block using Census data for the latest available year. To do this, create a Raster map (or thematic map) of concentrations of people in a GIS software.
12. Identify major employment concentrations by census block using the latest available employment and shapefile data from Census LEHD website. To do this, create a Raster map (or thematic map) of concentrations of jobs in a GIS software.
13. For an existing route, add the existing transit route configuration and stops to the map.
14. For a new route, use the thematic maps to determine the general alignment for the route to connect high intensity centers.
15. Identify cross route locations for transfers and add them to the map
16. For an existing route, add a database of amenities (shelter, benches, route maps, etc.) present at individual stop locations and add them to the map. These can help in determining stops to retain where choices need to be made between adjacent locations.
17. Identify primary stop locations from the previous steps.
18. Create buffers of 0.25-mile radius around the primary stops for most types of built environments and 0.125-mile radius for the dense urban environments.
19. For an existing route, use the buffers to determine where there is too much overlap so as to flag potential stops for elimination or re-positioning; in other areas, use the buffers to identify intermediate locations to achieve convenient, walkable access from nearby land uses.
20. For new routes, use the buffers to determine intermediate locations to achieve convenient, walkable access from nearby land uses.

### 9.2.4 Public Input

Once the stop placement is completed, public input is desirable. First it would serve as a forum to inform the riding public or potential riders about the rationale for selecting stop locations. It would also help in choosing from alternative locations that are close to each other and in confirming transfer and connection points identified from data. Public input can help in

determining which stop removals could have significant adverse impacts on such disadvantaged groups as the transit-dependent, elderly, or disabled. It can also help to identify issues that may be associated with the placement of certain stops.

### **9.2.5 Site-Specific Treatments**

Following the general demarcation of stop locations, site-specific adjustments and treatments may become necessary. These types of scenarios are dealt with in TCRP Report 19 (1996). They deal with issues related to the needs of passengers who would use the transit route, accessibility and appropriateness of the site for pedestrians, characteristics of the streets which the transit route traverses and placement near or far from intersections. The key issues and criteria are summarized in subsection 2.5 of the literature review.

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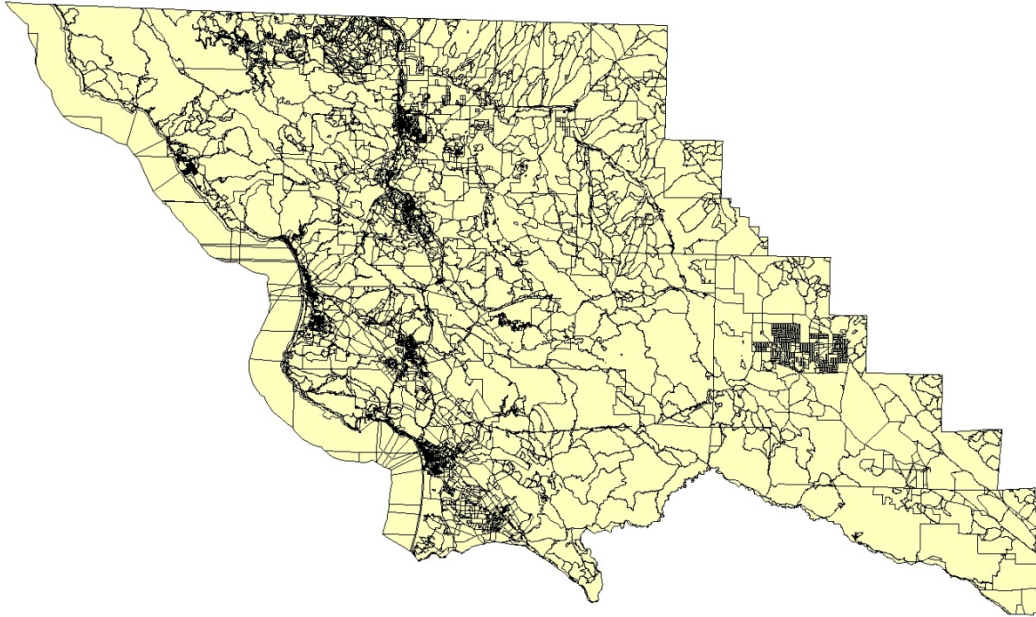
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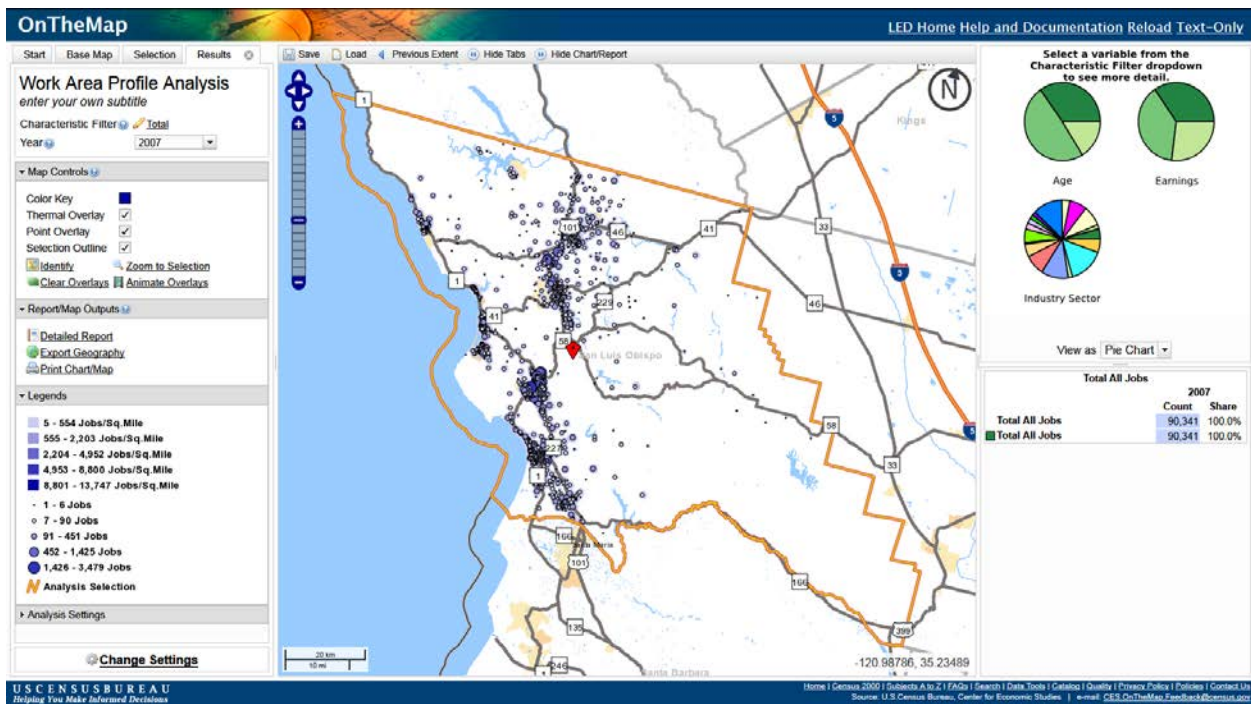
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## Appendix 6-1: Additional Details - RTA Routes (#9 and #10)

Step 1: Retrieve initial data



Step 2: Retrieve employment data based on census blocks from LEHD.



Step 3: Create raster layers in GIS (this illustration used ArcGIS 10)

Step 4: Produce final employment and population images.

Step 5: Choose routes for analysis.

Step 6: Mark significant locations along each route.

Step 7: Mark potential transfer locations.

(Pink points)

Step 8: Mark key locations along the route.

(Blue points)

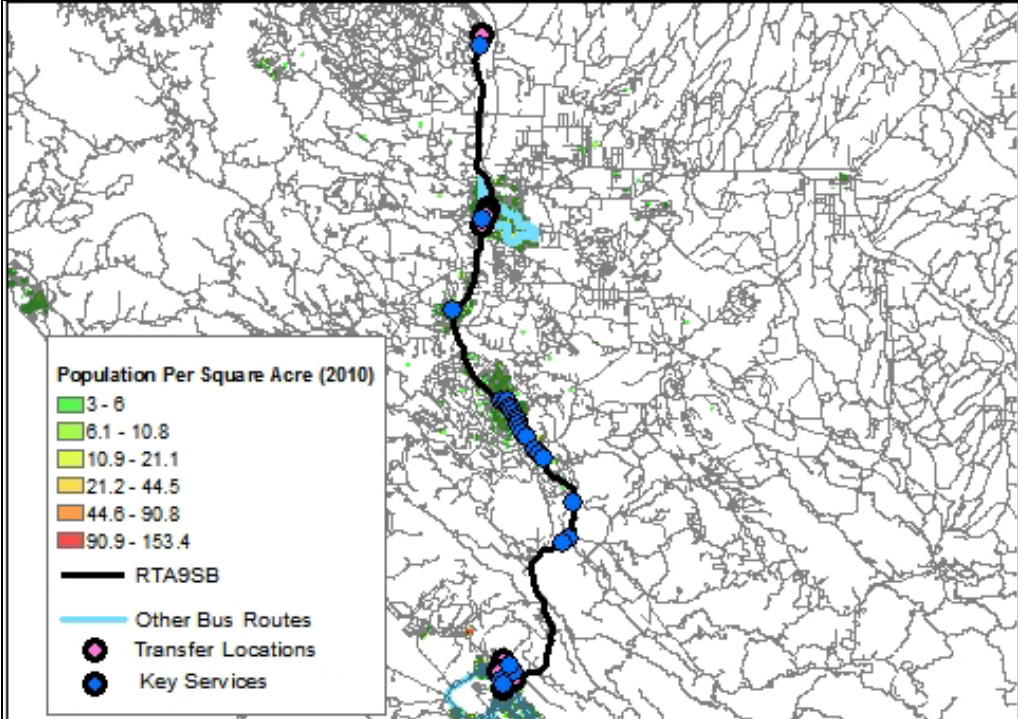
Step 9: Determine segments with steep slopes, which might therefore have different stop spacing requirements.

No steep slope segments Identified for any of the RTA routes.

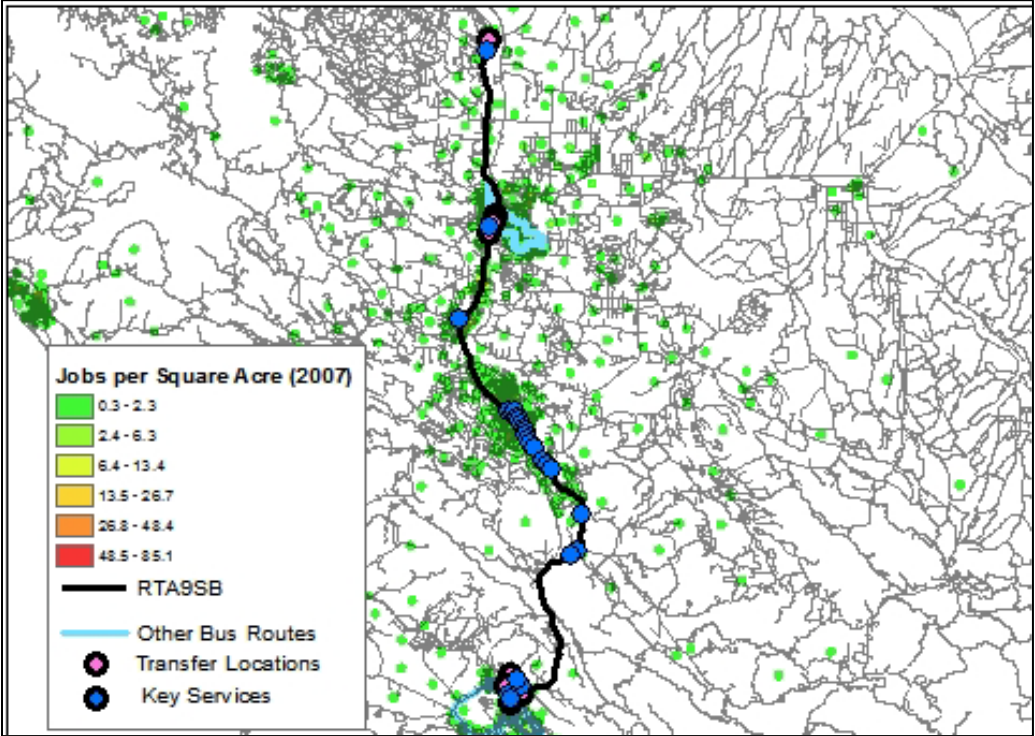
Step 10: Place stops along route considering all previously discussed factors.

(Green points)

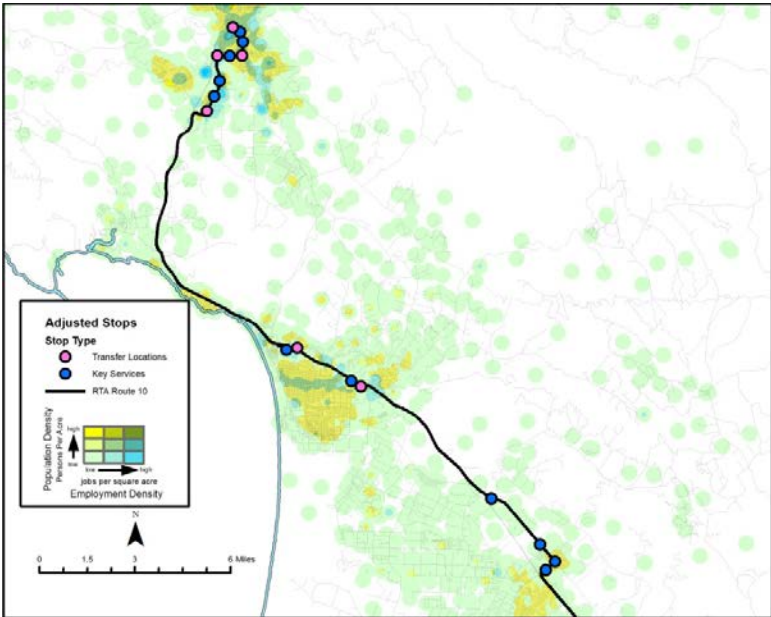
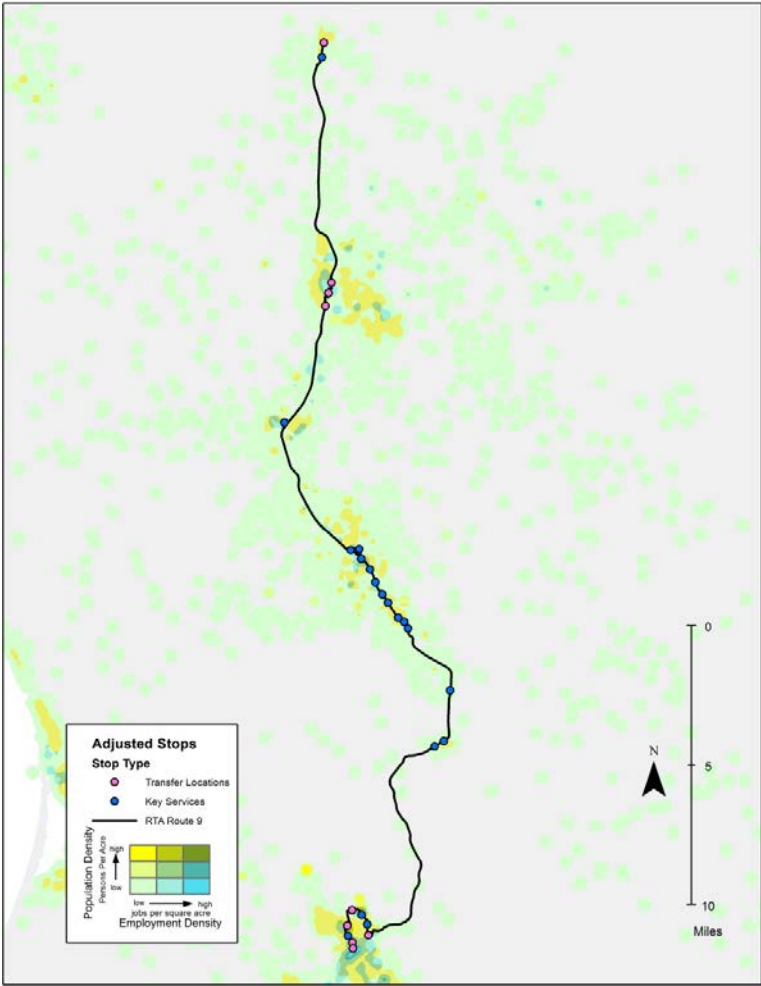
Completed Placement of Stops vs. Population Density (RTA Routes 9 and 10)



Completed Placement of Stops vs. Employment Density (RTA Routes 9 and 10)



Completed Placement of Stops vs. Combined Activity Centers (RTA Routes 9 and 10)



## Appendix 6-2: Combined Raster Process

The following steps describe the procedure for producing a raster surface which combines population and employment densities. In order to perform this operation, you should first have a raster surface which symbolizes population density, and a separate raster surface which symbolizes employment densities. With both of these surfaces loaded into ArcMap, you can begin the combination procedure.

- 1) Determine non-overlapping segments of the population and employment rasters.
  - a) Access ArcToolbox
  - b) Select Spatial Analyst Tools > Conditional > Set Null
  - c) To determine sole employment locations
    - i) Input conditional raster : **Current Population Raster**
    - ii) Input false raster or constant value: **Current Employment Raster**
    - iii) Output Raster : **Your workspace folder**
    - iv) Click OK. ArcGIS will produce a raster which shows locations of **sole employment density**.
  - d) To determine sole population locations
    - i) Input conditional raster : **Current Employment Raster**
    - ii) Input false raster or constant value: **Current Population Raster**
    - iii) Output Raster : **Your workspace folder**
    - iv) Click OK. ArcGIS will produce a raster which shows locations **of sole population density**.

Note: This step is necessary because the Combine tool which is used in step 4 to combine the population and employment rasters will only produce output within cells where there is both an overlaying population AND employment value. If an output cell is overlain by only one of the values, that cell will be represented as 'No Data.' Step one ensures that these sole population/employment values are retained by creating the respective rasters.

- 2) Reclassify the original population and employment rasters.
  - a) Exclude the 0 values from the original population and employment rasters.
    - i) Access the layer properties for the rasters.
    - ii) Click the *Classify* button.
    - iii) Click the *Exclusion* button under 'Data Exclusion'.
    - iv) Input '0' in the 'Excluded Values' field.
    - v) Click *OK* on all windows until exit the layer properties.
  - b) Access Spatial Analyst > Reclass > Reclassify
  - c) To reclassify the population raster
    - i) Input raster : **Current Population Raster**
    - ii) Verify that the Reclass Field is set to **Value**

- iii) Click the *Classify* Button
  - iv) Choose the classification method which most appropriately symbolizes the spatial variation of the data, but will also let you choose the number of classes. Natural Breaks may work best in most cases. When reclassifying the data, it is important to create enough classes so that a 3 X 3 or 4 X 4 population/employment grid can be created. For a 3 X 3 grid, create at least four classes of population data. A similar number of classes should be created for the population data. Click *OK* to exit the classification menu.
  - v) In the top row of the 'Old Values/New Values' reclassification table, notice the first number of the range is 0. Change this to a small non-zero number, such as .000001.
  - vi) Check the box labeled 'Change missing values to NoData'.
  - vii) Set the Output Raster to save in your workspace folder with a descriptive name such as **PopReclass**.
  - viii) Repeat the above steps for the reclassification of the employment raster. Be sure that the 0 values are excluded from the symbology of the original employment raster before you proceed with the reclassification.
- 3) Combine the Reclassified Population and Employment rasters created in the previous step.
- a) In ArcToolbox, select the Combine tool. Spatial Analyst > Local > Combine
  - b) Select the reclassified population and employment rasters as the input rasters.
  - c) Set the output raster to save in your current workspace.
  - d) Click *OK*.
- 4) Symbolize the output combined pop/emp raster for display.
- a) Access the attribute table for the combined population/employment raster.
  - b) Sort by the reclassified population field.
  - c) Notice the unique pairs of population and employment classifications. For instance, the first population class is separately paired with each intersecting employment classes. These pairs will form the basis of the symbolization. Each unique pair should have a unique value assigned to it. See the table below for an example:



Rowid	VALUE *	COUNT	RECLASS_POP18	RECLASS_EMP20
0	1	956528	1	1
2	3	52087	1	2
8	9	1870	1	3
10	11	298	1	4
1	2	263491	2	1
4	5	47334	2	2
7	8	2142	2	3
9	10	117	2	4
3	4	935	3	1
5	6	900	3	2
6	7	545	3	3

Cells with a '1' under the 'Reclass\_POP' field represent cells with the lowest population values from our original population raster. Each of these low values is paired with a value from the 'Reclass\_EMP' field, which represents the employment values from the original raster. A pairing of 1:1 represents the lowest possible value for combined population and employment density. A pairing of 4:4 would represent a highest possible combination of population and employment density. In the example above, however, there is no fourth population class which intersects with any employment data (There is a fourth population class, but it is only available in the sole population raster which we created in step 1). Additionally, the fourth employment class only intersects with the first and second population classes. In this case, the analyst should subsume these 4th class employment values into 3rd class values, while retaining the respective population classes for the rows (The 1:4 pair will become 1:3, and the 2:4 pair will become 2:3). The resulting operation will result in 9 unique pairings, which can then be used to create a 3X 3 grid. Meanwhile, the fourth population class (which isn't represented in the table above, but is represented in the sole population layer created in step one) will be subsumed into the third population class in the next step.

At this point, the analyst should decide on a color scheme in order to symbolize the data. Unique colors should be assigned according to the 'VALUE' field, which is the identifier for each unique class pair. Other image manipulation programs may need to be used to determine the most effective color values for each unique pair.

- 5) Symbolize the sole population and employment rasters appropriately.

a) The sole Population and Employment rasters represent the left and bottom rows of the 3 X 3 or 4 X 4 density grid, respectively., and thus should be symbolized as a gradual change in intensity of the base colors. The colors for these should match the appropriate colors for the combined density raster. In the example below, the first classes for the sole population and employment density colors match each other. They also match class VALUE 1, in the combined raster, because any cells with a 1:1 pairing to represent similarly low values in population and employment density, only they are now combined in that particular layer. The second sole population class color matches Combined layer VALUE of 2 (2:1) pairing. The third sole population class matches the Combined layer VALUE of 4 (3:1) pairing. As explained earlier, the fourth population class does not intersect with any employment values, so it is given the same color as the third population class.

For the sole employment layer, the second class color should match the Combined layer VALUE of 3 (1:2 pairing). The third class color should match the Combined layer VALUE of 9 (1:3 pairing). As mentioned before, because it is a 3 X 3 grid, the fourth employment class will be folded into the third, and so the fourth sole employment class will take the same color as the third class.

The screenshot shows a GIS software interface with a 'Layers' panel on the left and a data table for the 'Combined Employment Density Layer' on the right.

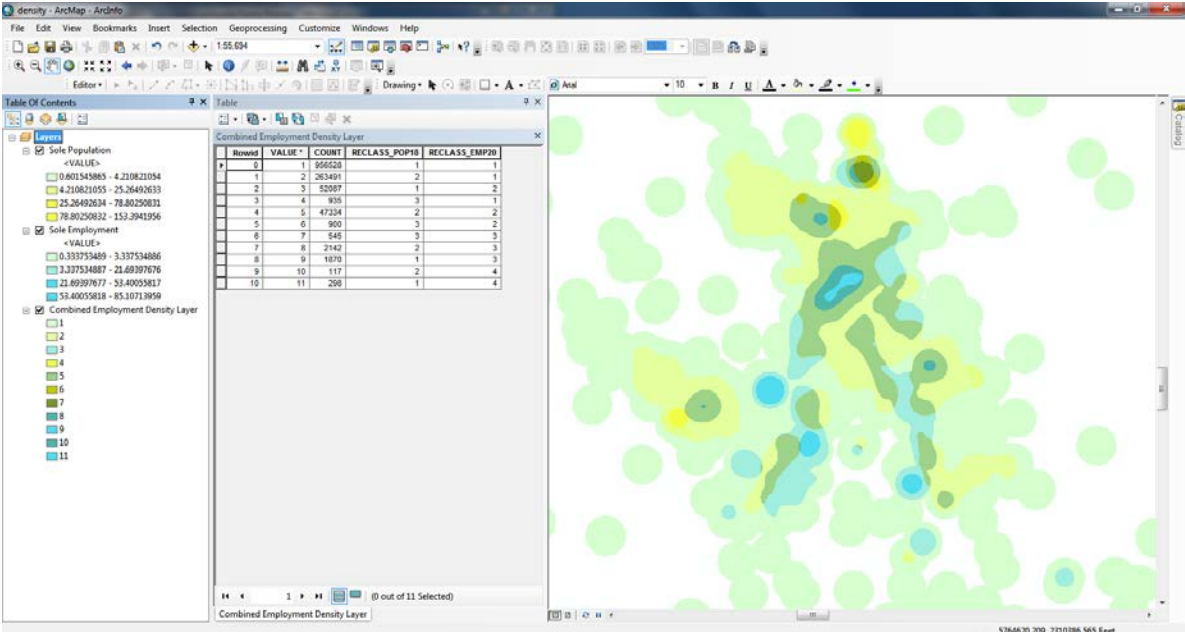
**Layers Panel:**

- Sole Population
  - <VALUE>
  - 0.601545865 - 4.210821054
  - 4.210821055 - 25.26492633
  - 25.26492634 - 78.80250831
  - 78.80250832 - 153.3941956
- Sole Employment
  - <VALUE>
  - 0.333753489 - 3.337534886
  - 3.337534887 - 21.69397676
  - 21.69397677 - 53.40055817
  - 53.40055818 - 85.10713959
- Combined Employment Density Layer
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10
  - 11

**Combined Employment Density Layer Table:**

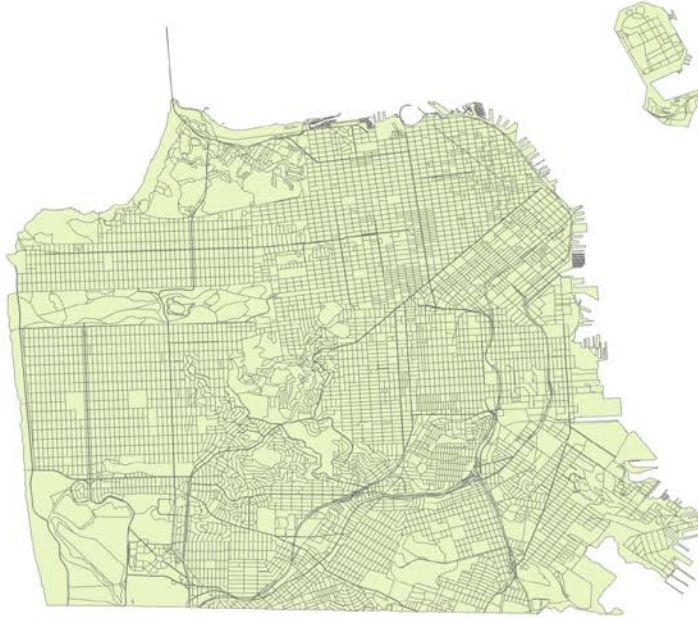
Rowid	VALUE *	COUNT	RECLASS_POP18	RECLASS_EMP20
0	1	956528	1	1
1	2	263491	2	1
2	3	52087	1	2
3	4	935	3	1
4	5	47334	2	2
5	6	900	3	2
6	7	545	3	3
7	8	2142	2	3
8	9	1870	1	3
9	10	117	2	4
10	11	298	1	4

Once the colors are assigned to the sole population and employment layers and the combined layer, all three layers can be displayed to illustrate a composite raster surface.

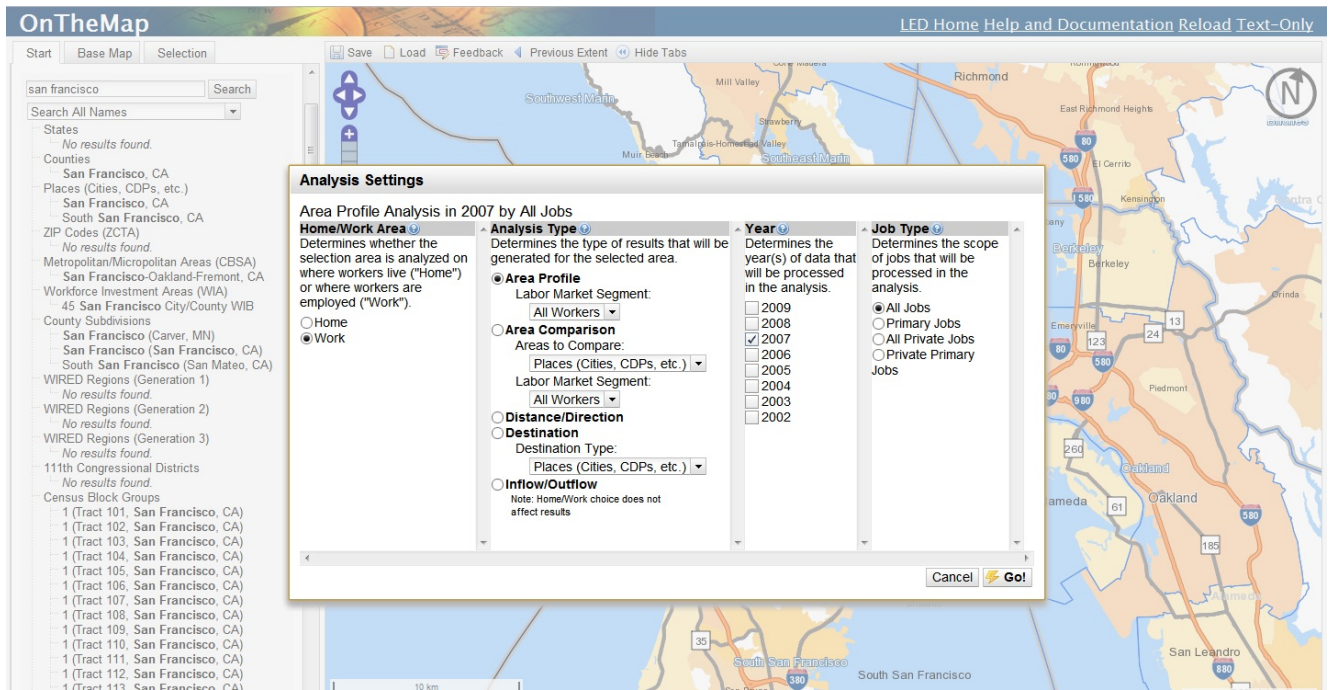
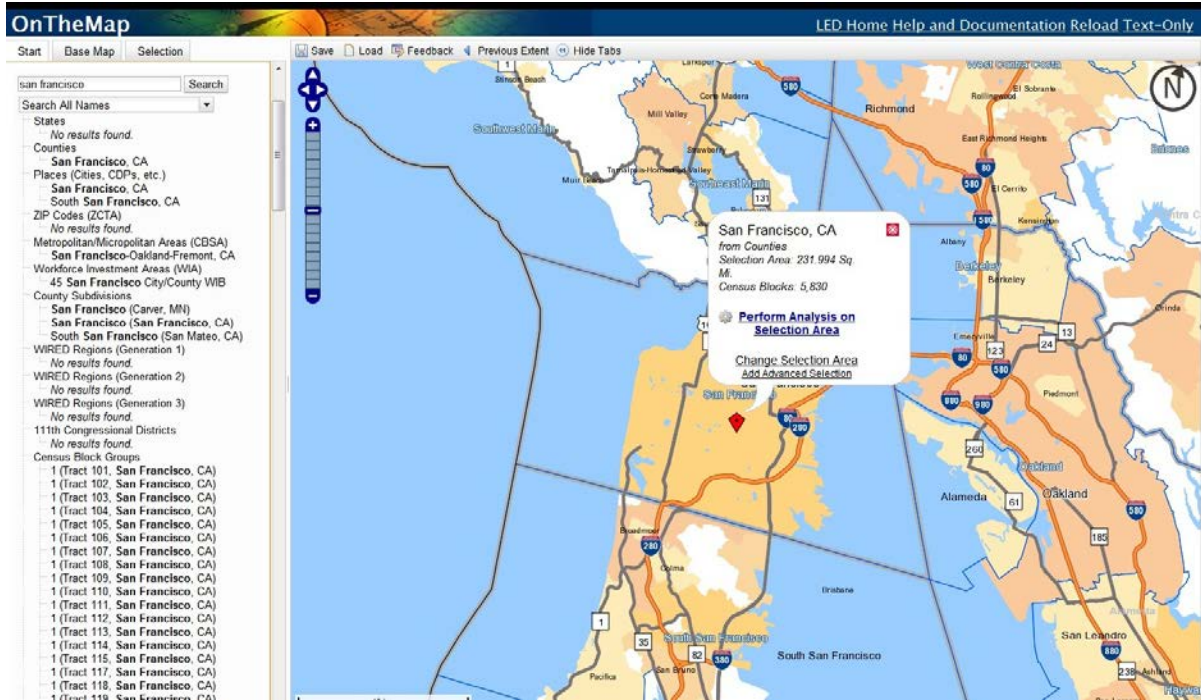


## Appendix 7-1: Additional Details - SFMTA Routes

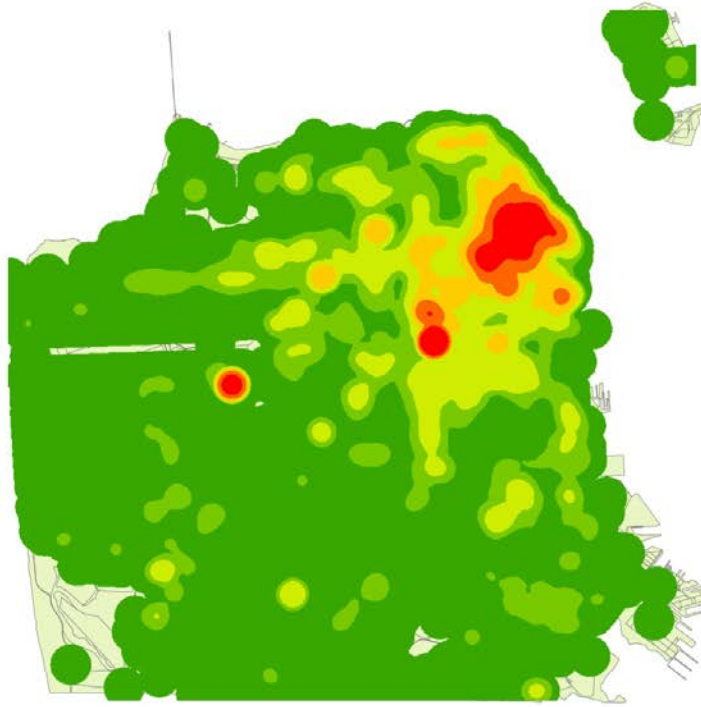
Step 1: Retrieve initial data



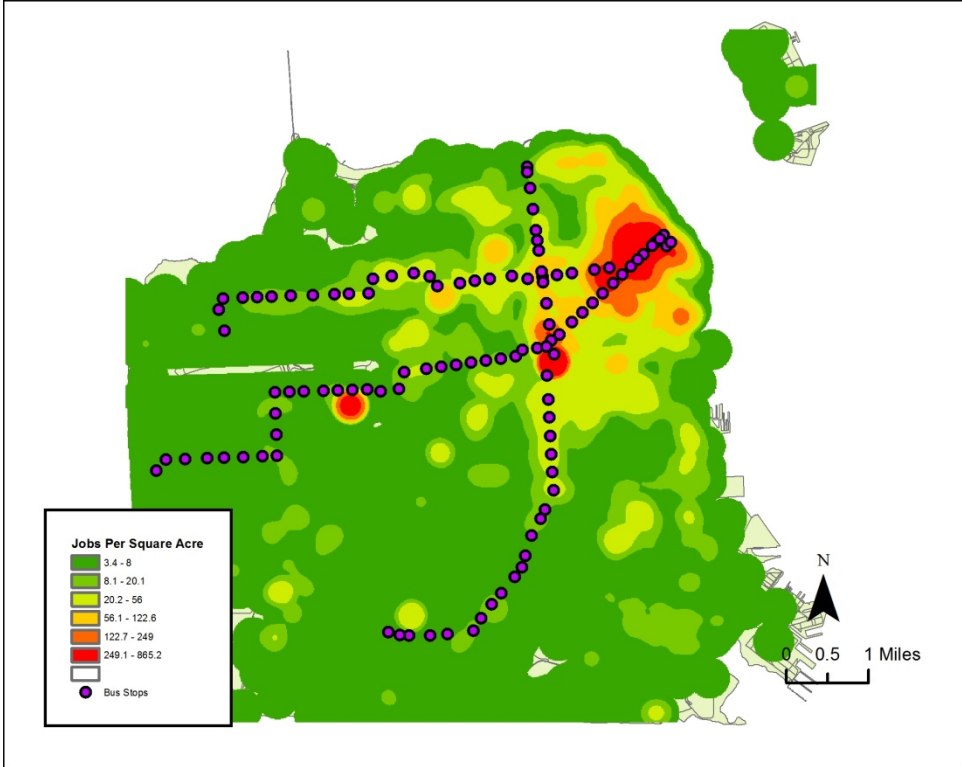
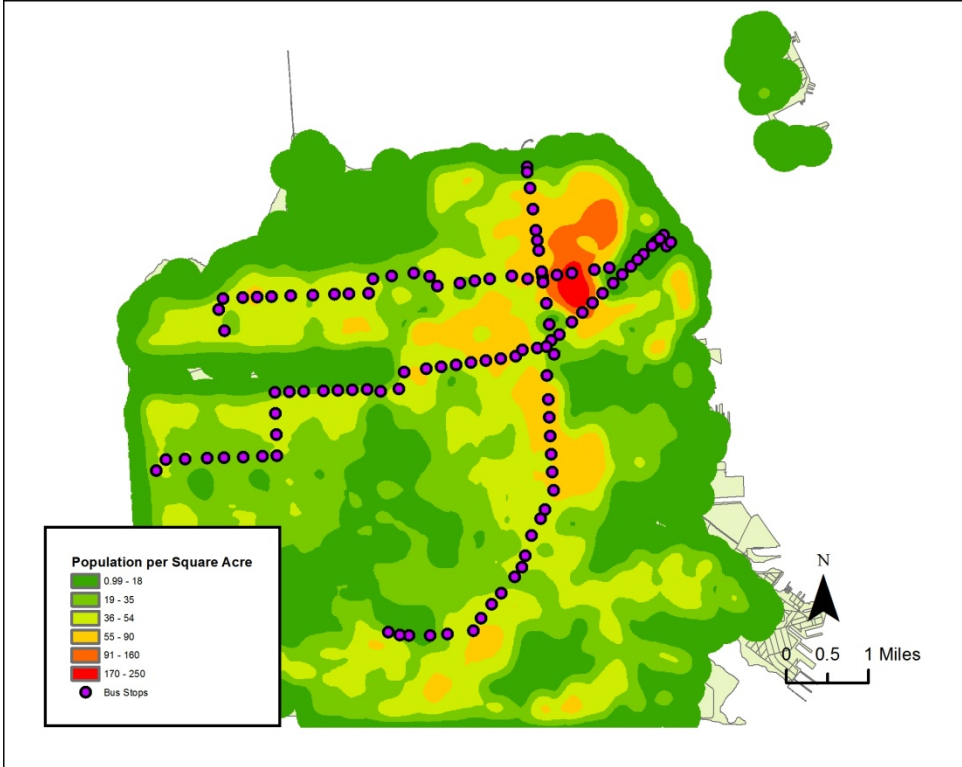
Step 2: Retrieve employment data based on census blocks from LEHD.



Step 3: Create raster layers in GIS



Step 4: Finalize population and employment images



Step 5: Choose routes for analysis

Step 6: Mark significant locations along each route.

Step 7: Mark potential transfer locations.

Step 8: Mark key locations along the route.

Step 9: Determine segments with steep slopes, which might therefore have different stop spacing requirements.

Step 10: Place stops along route considering all previously discussed factors.

