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Feasibility Study for a Bicycle Sharing Program in Sacramento, California

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1 **ABSTRACT**

2 This study presents a methodology for analyzing the feasibility of bicycle sharing programs based on U.S.
3 experiences. While past studies have had to rely on observations from European systems, the recent
4 emergence of several large-scale programs in the U.S. creates an important opportunity to explore the
5 determinants of bike-share use in a more relevant context. This understanding will lead to more effective
6 strategies for promoting the bike-share mode in pursuit of reduced congestion, enhanced air quality, and
7 improved public health.

8 This project analyzed recent data from a bicycle sharing program in Minneapolis (the “Nice
9 Ride” program) and applied the findings to Sacramento, where a program is currently being considered. A
10 regression analysis of Nice Ride rentals was conducted to identify the determinants of monthly rentals
11 and to establish a predictive model. These findings were then evaluated in Sacramento to recommend a
12 program service area and predict ridership. First, a weighted sum raster analysis was performed to
13 identify suitable locations for a program and to recommend service areas. Second, the coefficients of the
14 Nice Ride regression model were applied to characteristics of the recommended service areas to predict
15 ridership. Estimated ridership ranged between 26,864 and 28,266 rentals per month. These estimates can
16 be used to predict program revenues and facilitate effective decision-making. The study also found that
17 underlying differences between Minneapolis and Sacramento played a key role in the results, indicating
18 that this methodology should be repeated for pairs of more similar cities as data from more U.S. programs
19 become available.

1 INTRODUCTION

2 As concerns related to energy dependence, rising greenhouse gas emissions, and decreasing physical
3 activity levels have become more pressing, significant attention has been devoted to the roles of walking
4 and cycling in generating healthier and more sustainable travel patterns. One approach to the promotion
5 of the cycling mode has been the development of bicycle sharing programs, which provide subscribers
6 with short-term bicycle access in an automated and increasingly flexible manner (1).

7 Although bicycle sharing programs are becoming considerably popular, they entail large financial
8 investments for bicycles, stations, technology, maintenance, and bicycle redistribution. Moreover, the
9 literature is currently limited in its treatment of the cost effectiveness of these programs. However, the
10 popularity and potential benefits associated with bicycle sharing programs make it unlikely that the trend
11 will wait for the literature to fully analyze cost effectiveness. In the meantime, it will be important for
12 planners to assess the feasibility of this approach within a local context.

13 This project evaluates the potential for a bicycle sharing program in the city of Sacramento,
14 California. The methodology used in this study, which builds upon the strengths and addresses the
15 limitations of past work, will provide a framework for the evaluation of potential programs in U.S. cities.
16 Importantly, while past studies have had to rely on European figures, this study has been carried out at a
17 time when information is emerging from programs recently implemented in the U.S. Thus, this project
18 will make use of patterns and data that are perhaps more appropriate to the U.S. context.

19 PREVIOUS STUDIES

20 Although a number of studies have addressed the potential benefits of bicycle sharing programs, few have
21 evaluated their costs in comparison to alternative planning and policy approaches. This attests to the
22 importance of careful analysis before implementation. Several authors have developed feasibility studies
23 that recommend locations and predict ridership for programs in specific cities, and the current project
24 builds upon the strengths and limitations of these studies.

25 Several approaches have been used to recommend service areas for proposed bicycle sharing
26 programs. The most systematic and comprehensive approach is taken by Krykewycz et al (2010), who
27 conduct a weighted sum raster analysis to determine bike-share suitability throughout Philadelphia and to
28 map core and expanded service areas (2). Their suitability analysis focuses on variables such as population
29 and job density; locations of tourist attractors and bus stops; and proximity to parks, rail stations, and bike
30 lanes. The authors divide the city into a grid, calculate a combined suitability score for each cell based on
31 these factors, and delineate program boundaries based on the distribution of suitability scores.

32 The current project builds upon this general methodology but differs in two key respects. First, while
33 the approach taken by Krykewycz et al (2010) is systematic, it does not account for important factors such as
34 demographic and socioeconomic conditions, transit intensity, and vehicle ownership. These factors are
35 included in the current study for a comprehensive set of indicators. Second, Krykewycz et al (2010) select
36 suitability inputs based on theory, while recent ridership data will allow the current study to base the
37 inclusion and direction of inputs on an empirical analysis of existing program experiences.

38 The feasibility studies conducted for Vancouver, New York City, and central London also attempt to
39 define program service areas, although their methods are less systematic. In their analysis of a potential
40 program in Vancouver, representatives from Quay Communications, Inc. develop a series of success
41 indicators and measures to evaluate different neighborhoods, but the findings are not quantified (3). While
42 the authors of *Bike-Share Opportunities in New York City* define and map a series of variables deemed
43 important to program success, the variables are treated only individually and the authors do not synthesize
44 the findings into a recommendation for program location and extent (4). Finally, the authors of a feasibility
45 study for a system in London identify and map 149 land areas currently available for stations, offering a
46 general idea of potential program extent; however, the authors note that some of the identified areas may
47 prove unsuitable due to limited demand and technical issues (5). This calls attention to the limitations of
48 conducting spatial analysis without considering land suitability and bike-share demand.

49 These four feasibility studies also estimate bike-share ridership, with methods based primarily on
50 existing trip patterns and observations from European programs. Krykewycz et al (2010) evaluate pre- and
51 post-program trip patterns in Lyon (France), Barcelona, and Paris to calculate the rates at which users of
52 other modes are drawn to bike-share programs (2). The authors multiply these diversion rates by pre-

1 program trip patterns in Philadelphia to estimate diverted users. Similarly, the authors of the Transport for
 2 London feasibility study evaluate trips originating and terminating within a specified geographical area and
 3 multiply these values by a proportion, as determined through market research, representing the likelihood
 4 that other mode users will switch to the new program (5).

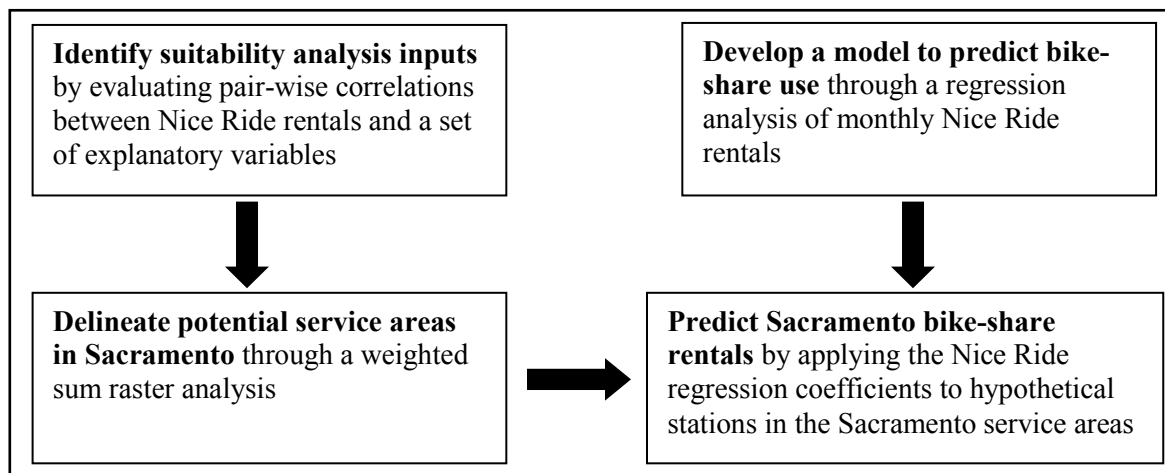
5 While the applicability of examples from European programs is somewhat questionable, the analyses
 6 conducted for Philadelphia, Vancouver, and New York City each use observations from existing programs in
 7 Europe to estimate demand in the North American context. This practice, resulting from limited programs
 8 and data availability in the U.S., does not account for contextual differences or key transportation and built
 9 environment factors that are likely to influence bike-share demand. The current study benefits from the
 10 recent release of data from one of the first U.S. programs, thus addressing this limitation.

11 **APPROACH**

12 This project used a combination of regression and spatial analysis to recommend suitable locations for a
 13 bicycle sharing program in Sacramento and to estimate ridership within these areas. While past studies
 14 have relied on theory to evaluate bike-share suitability, this project used an empirical approach, based on
 15 observations from the “Nice Ride” program in Minneapolis, to understand the determinants of bike-share
 16 rentals and apply the findings to the Sacramento context. This approach involved the following steps:

- 17 • Identify key factors that determine how suitable an area is for bike-share use, based on the
- 18 distribution of rentals across Nice Ride stations
- 19 • Develop a regression model that most effectively explains Nice Ride rentals by station
- 20 • Delineate potential service areas for a program in Sacramento
- 21 • Estimate bike-share rentals in Sacramento within these proposed service areas

22 These steps were addressed through various analytical techniques, as indicated in Figure 1.



23 **FIGURE 1 Project Methodology**

24 First, to understand the determinants of bike-share rentals, a regression analysis was performed
 25 using Nice Ride stations as observations (n=65) and the log of the number of August 2010 rentals by
 26 station as the dependent variable. A variety of independent variables were included to account for factors
 27 believed to be important in explaining ridership. The pair-wise correlations between each independent
 28 variable and monthly rentals were examined to identify influential factors that should be included in a
 29 GIS suitability analysis. The independent variables were then used to develop a regression model aimed at
 30 predicting bike-share rentals.

31 The suitability inputs and predictive model were then applied to conditions in Sacramento in
 32 order to identify service areas and predict ridership. All explanatory variables were mapped across a study
 33 area consisting of the Sacramento city limits, a portion of West Sacramento, and several areas just outside
 34

1 of the city limits. This study area was defined based on data availability and input from local officials.

2 To recommend service areas in Sacramento, GIS layers for the identified suitability inputs were
3 rasterized (transformed into a grid) across the study area, and a weighted sum raster analysis was
4 performed. Conceptually, this technique overlaid the rasterized layers and measured the bike-share
5 suitability of each grid cell based on the sum of the layer values. Two potential service areas were drawn
6 to connect areas with the highest suitability scores.

7 Finally, the values for all explanatory variables were measured for a series of hypothetical
8 stations within these service areas and the coefficients of the full Nice Ride regression were applied to
9 predict monthly rentals in Sacramento. Alternative scenarios and confidence intervals were used to
10 estimate a range of potential rental values for the proposed program.

11 DATA

13 The log of the number of August 2010 rentals, by station, served as the dependent variable in the Nice
14 Ride analysis. The independent variables in the analysis accounted for a variety of trip generation, trip
15 attraction, and transportation network factors. The majority of these variables were measured within a
16 400-meter buffer around each station to reflect a typical walking distance of approximately one-quarter
17 mile. All independent variables were collected for both cities, as they were first used in the empirical
18 analysis of Nice Ride rentals and then evaluated within the Sacramento context. Definitions for all
19 variables are presented in Table 1.

21 **TABLE 1 Definitions of Project Variables**

Variable	Definition (with units, as applicable)
Dependent	
<i>ln(Rentals)</i>	Natural log of the number of rentals during August 2010, by station
Independent	
<u>Trip Generation Factors</u>	
<i>Population</i>	Total population (in 100s of persons)
<i>Non-White Population</i>	Proportion of population that is of a race other than “white alone”
<i>Low-Vehicle Households</i>	Proportion of households that have one or zero vehicles available
<i>Income</i>	Median household income (in 1000s of dollars)
<i>Alternative Commuters</i>	Proportion of workers who commuted by bicycle, walking, or public transportation before 2010 (in 100s of workers)
<i>High-Income Jobs</i>	Number of workers who earn more than \$3,330 per month (in 100s of workers)
<u>Trip Attraction Factors</u>	
<i>Jobs</i>	Jobs within “appropriate” ^a NAICS sectors (in 100s of jobs)
<i>Retail Jobs</i>	Retail jobs (in 10s of jobs)
<i>Attractors</i>	Number of “attractors” (shopping centers, cultural/historic/civic sites, sports complexes, entertainment centers, museums, etc.)
<i>College</i>	1 if a college is located within 400 meters of a station, 0 otherwise
<i>Distance to Park</i>	Distance to nearest park/recreation site (in 10s of meters)
<u>Transportation Network Factors</u>	
<i>Transit Intensity</i>	Bus/rail vehicles serving the area per hour during the AM peak (in 10s of vehicles)
<i>Bus Stops</i>	Number of bus stops (in 10s of stops)
<i>Distance to Rail</i>	Distance to nearest light/commuter rail stop (in 100s of meters)
<i>Bikeways</i>	Length of existing bike lanes and paths (in 100s of meters)
<i>Bike-Share Spaces</i>	Number of spaces/docks offered at a station

^a “Appropriate” jobs are those within North American Industry Classification System (NAICS) sectors deemed to be appropriate for bike-share use, as destinations for both employees and patrons

1 RESULTS

3 Identification of Suitability Analysis Inputs

4 First, Nice Ride rental patterns were analyzed to identify the factors that most strongly influence bike-
 5 share ridership and therefore justify inclusion in the Sacramento suitability analysis. Due to high
 6 collinearity among the variables (affecting the results under various regression techniques), it was
 7 appropriate to select suitability inputs based on the pair-wise correlations between each independent
 8 variable and monthly rentals rather than on the results of a full regression model. However, the
 9 standardized coefficients for a preliminary model of all variables in Table 1 indicated that *Jobs* and *High-*
 10 *Income Jobs* had a particularly strong influence on Nice Ride rentals. These two variables were therefore
 11 found to be appropriate inputs for the suitability analysis.

12 Due to their influence, *Jobs* and *High-Income* were also used as controls in a series of adjusted
 13 pair-wise correlations between each remaining variable and monthly rentals. This approach, as
 14 summarized in Table 2, determined which variables shared a significant relationship with rentals even
 15 after controlling for these two highly influential factors.

17 **TABLE 2 Adjusted Pair-Wise Correlations between Each Variable and Monthly Nice Ride Rentals**
 18 **(adjusted for *Jobs* and *High-Income Jobs*)**

Variable	Coefficient	Standard Error	p-value
<i>Non-White Population</i>	-3.128	0.422	0.00***
<i>Income</i>	0.029	0.005	0.00***
<i>Alternative Commuters</i>	8.327	2.420	0.00***
<i>Distance to Park</i>	-0.009	0.005	0.10*
<i>Distance to Rail</i>	0.019	0.011	0.10*
<i>Low-Vehicle Household Prevalence</i>	1.064	0.685	0.13
<i>Bus Stops</i>	0.020	0.014	0.15
<i>Home Destination</i>	0.046	0.033	0.17
<i>Bikeways</i>	0.008	0.007	0.26
<i>Transit Vehicles</i>	0.020	0.019	0.31
<i>Retail Jobs</i>	0.006	0.005	0.32
<i>Attractors</i>	0.044	0.045	0.33
<i>Work Destination</i>	0.100	0.128	0.44
<i>College</i>	-0.166	0.262	0.53
<i>Population</i>	-0.006	0.014	0.66

*, **, and *** indicate statistical significance at the 10, 5, and 1 percent levels, respectively.

20 Table 2 shows that five variables were found to have a significant relationship with rentals even
 21 after controlling for the effects of *Jobs* and *High-Income Jobs*. Interestingly, the unexpected positive sign
 22 of the *Distance to Rail* coefficient suggests that greater distances from rail stations are associated with
 23 higher bike-share rentals. This finding suggests that rail and bike-share may represent competing modes
 24 in the Minneapolis context. Similarly, the negative association between *Jobs* and *ln(Rentals)* could
 25 suggest that when all other factors are held equal, bike-share use is not as prevalent in employment
 26 centers that may be highly walkable and well-served by alternative, competing modes. Additionally, this
 27 finding could suggest a high degree of recreational use, as supported by the coefficient for *Distance to*
 28 *Park* (higher rentals closer to parks).

30 This analysis suggested a total of seven significant inputs, as well as their respective directions, to
 31 be included in an analysis of bike-share suitability in Sacramento.

33 Development of a Regression Model to Predict Bike-Share Rentals

34 Next, the preliminary regression was refined to develop a predictive model of bike-share rentals based on
 35 the Nice Ride experience. Given this purpose, measures of fit rather than variable significance were

emphasized in model selection. A variety of model inputs were tested, resulting in a preferred model (presented in Table 3) that could be used to predict monthly rentals for the proposed Sacramento program.

TABLE 3 Results of Preferred Regression of Monthly Nice Ride Rentals (n=65)

Variable	Coefficient	Standard Error	p-value
<i>Non-White Population</i>	-2.522	0.770	0.00***
<i>Distance to Park</i>	-0.013	0.004	0.00***
<i>Income</i>	0.015	0.006	0.01**
<i>Low-Vehicle Households</i>	-1.909	0.832	0.03**
<i>High-Income Jobs</i>	0.068	0.033	0.04**
<i>Jobs</i>	-0.059	0.028	0.04**
<i>Bike-Share Spaces</i>	0.028	0.014	0.05*
<i>Alternative Commuters</i>	5.405	3.146	0.09*
<i>Retail Jobs</i>	0.010	0.006	0.09*
<i>Attractors</i>	0.051	0.034	0.14
<i>Bus Stops</i>	0.014	0.011	0.20
<i>Distance to Rail</i>	-0.014	0.013	0.27
<i>Transit Intensity</i>	-0.008	0.015	0.58
<i>College</i>	0.102	0.201	0.61
<i>Population</i>	-0.001	0.014	0.94
<i>Bikeways</i>	-0.000	0.005	0.99
<i>Constant</i>	5.672	0.971	0.00
R ²		0.7362	
Adjusted-R ²		0.6483	
F (Prob > F)		8.37 (0.0000)	

*, **, and *** indicate statistical significance at the 10, 5, and 1 percent levels, respectively. R², adjusted-R², and F values are for the entire model including all variables, regardless of statistical significance.

The preferred model contains a total of nine statistically significant independent variables. Interestingly, the model offers insight into several socioeconomic variables with ambiguous theoretical relationships with bike-share ridership. Based on the Nice Ride experience, rentals can be expected to be higher in areas with higher median incomes, greater densities of high-earnings jobs, lower minority presence, and lower proportions of households with one or zero vehicles available. However, these results must be interpreted with caution. It is important to recognize that the model considers only spatial data without incorporating user-based inputs; that rental values were recorded during an early stage of the program when a full behavioral shift may not have occurred among all population groups; and that the provision of services based on these findings could have significant equity implications. These findings may also indicate that certain groups may be more effectively attracted to bike-share through outreach and alternative fare structures.

With the exception of *Jobs*, the directions of the remaining significant variables in the preferred model are as expected. As previously noted, the unexpected finding for job density could suggest modal competition or a high degree of recreational use.

It is important to recognize two caveats of this model. First, the high degree of collinearity among the variables may explain the insignificance of some theoretically important factors and may also obscure the true relationships between the variables in the model. Second, the model contains a large number of independent variables (X=16) relative to observations (n=65), which reduces its power. However, given available data, this model was found to be the best tool for predicting bike-share rentals.

Delineation of Bike-Share Service Areas in Sacramento

To define potential service areas, a weighted sum raster analysis was performed to calculate bike-share suitability throughout the Sacramento study area. GIS shapefiles for each of the seven identified

1 suitability inputs were rasterized (transformed into a grid) using 10 meter cells across the study area. Data
 2 for each layer were initially grouped into ten categories (based on either manual or Natural Breaks
 3 classification). These categories were then reclassified using a ten-point scale, with 10 representing the
 4 category most suitable for bicycle sharing. Combined suitability scores for each cell were calculated
 5 based on the sum of these reclassified inputs and then mapped according to a graduated color scheme
 6 across the study area. Based on this distribution, primary and secondary service areas were drawn to
 7 connect cells with high suitability values.

8 Methods of rasterization (transformation) and reclassification differed based on the type of input,
 9 as explained in Table 4. While the input directions for *Jobs* and *Distance to Rail* differ from those
 10 anticipated in theory, the pair-wise correlation findings were prioritized over theory in suitability
 11 construction due to their origin in actual Nice Ride experiences. As all inputs were based on variable
 12 significance, equal weights were assigned to all inputs.

13

14 **TABLE 4 Rasterization Methods for Suitability Analysis Inputs**

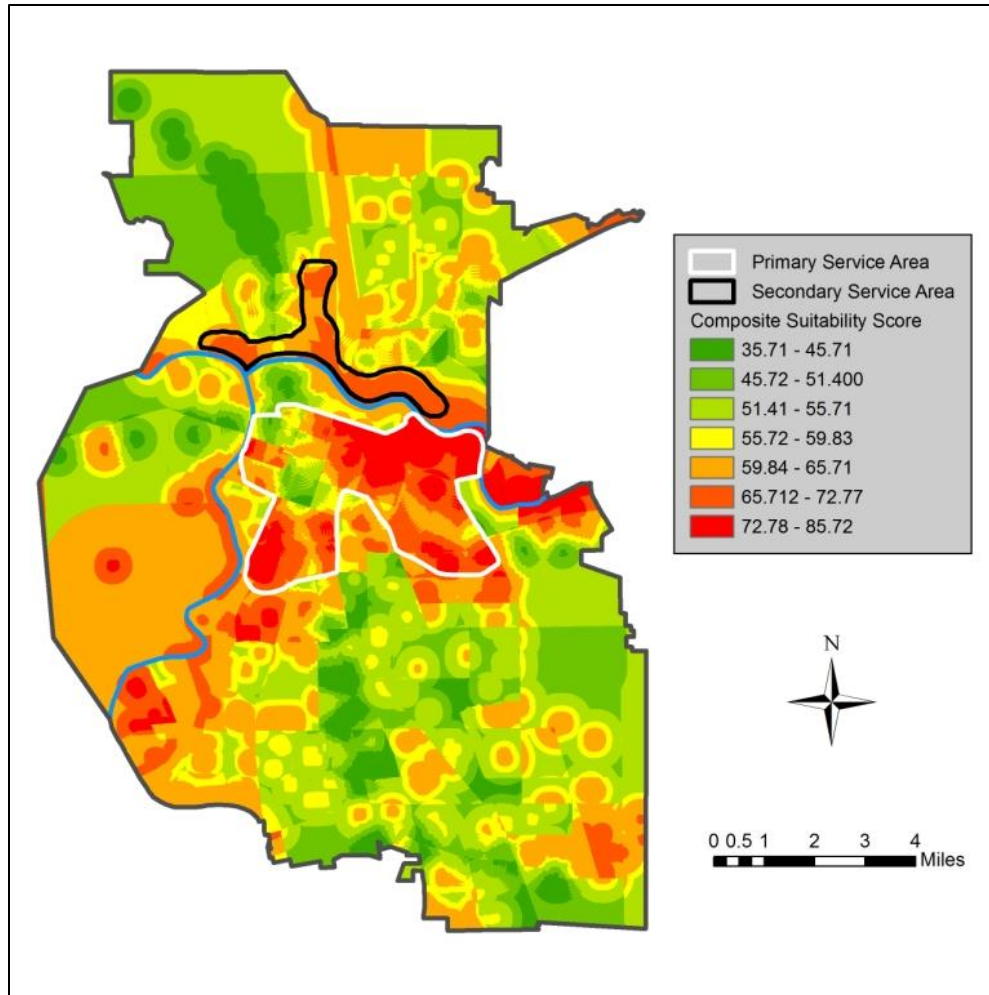
15

Layer	Field Rasterized	Method	Initial Grouping	Reclassification Direction
<i>Non-White Population</i>	Proportion of population that is of a race other than “white alone”	Value of Tract attributed to all cells whose centers fall within the Tract	Natural Breaks	Negative
<i>Income</i>	Median household income	“	“	Positive
<i>Alternative Commuters</i>	Proportion of workers who commute by bicycle, walking, or public transportation	“	“	Positive
<i>High-Income Jobs</i>	Workers per acre (by place of employment) earning more than \$3,333/month	“	“	Positive
<i>Jobs</i>	Total “appropriate” jobs per acre	“	“	Negative
<i>Distance to Park</i>	n/a	Distance between all cells and the nearest park calculated	Manual ^a	Negative
<i>Distance to Rail</i>	n/a	Distance between all cells and the nearest rail stop calculated	“	Positive

^a Manual: 10 bins with breaks at 100, 200, 300, 400, 500, 600, 700, 800, and 900 meters. This classification was chosen due to the presence of cells with very high values that fall outside of typical walking distances.

16

17 The spatial distribution of scores was used to map primary and secondary service areas for the
 18 proposed program. These boundaries were drawn to connect areas exhibiting the highest suitability, to
 19 incorporate the downtown area (located directly southeast of the confluence of the American and
 20 Sacramento Rivers), and to create a program comparable in size to the Nice Ride system. The boundaries
 21 were also overlaid with layers describing low-income and minority presence to ensure an equitable
 22 program, an important consideration given the direction of coefficients for these variables. Figure 2
 23 presents the suitability analysis results, with red indicating higher suitability, and the resulting program
 24 boundaries.



1
2 **FIGURE 2 Delineation of Primary and Secondary Service Areas in Sacramento**

3
4 The primary service area defined for Sacramento is approximately 12 square miles in area,
5 making it slightly larger than the Nice Ride program. This boundary encompasses the downtown area and
6 provides considerable extensions to the south and east in order to incorporate several outlying
7 concentrations of highly suitable cells. The secondary service area lies to the north of the American River
8 and its confluence with the Sacramento River, adding approximately 3 square miles to the program.
9

10 **Prediction of Monthly Bike-Share Rentals in Proposed Sacramento Service Areas**

11 The final phase of the project applied the results of the Minneapolis regression to the Sacramento context
12 in order to estimate ridership within the proposed service areas. This approach involved placing a series
13 of hypothetical bike-share stations throughout the Sacramento service areas; measuring values of the Nice
14 Ride regression variables for each station area; multiplying these values by their respective regression
15 coefficients; and summing these values to project monthly rentals for each station and for the entire
16 program. Two station placement schemes were evaluated to create low and high rental scenarios under an
17 average spacing similar to that of the Nice Ride program:
18

- 19 • *Scenario 1 (Low)* placed stations evenly throughout the service areas at 650-meter intervals,
20 resulting in 75 stations in the primary service area and 19 in the secondary service area. As this
21 spacing did not “over-sample” particularly suitable areas, Scenario 1 represented a low estimate.
- 22 • *Scenario 2 (High)* created a denser placement of stations (500-meter intervals) in a central
23 concentration of highly suitable cells, a less dense placement (800-meter intervals) outside of this
24 area, and the original 650-meter spacing in the secondary area. The number of stations in each

1 service area was the same as in Scenario 1. As this spacing “over-sampled” highly suitable areas,
 2 Scenario 2 represented a high rental estimate.

3
 4 A 400-meter buffer was placed around each Sacramento station to measure the values of all
 5 explanatory variables in the preferred Nice Ride regression. Values for *Bike-Share Spaces* were calculated
 6 based on the average number of spaces for central and outlying Nice Ride stations. The values for each
 7 variable were multiplied by their respective preferred-model coefficients and summed to calculate rentals
 8 per station. To account for empirical error, the confidence intervals of the estimates were evaluated. The
 9 results of this analysis are presented in Table 5, with the ranges implied by the confidence intervals
 10 indicated in parentheses below each estimate.

11 **TABLE 5 Projected Rentals under Alternative Station Placement Scenarios**

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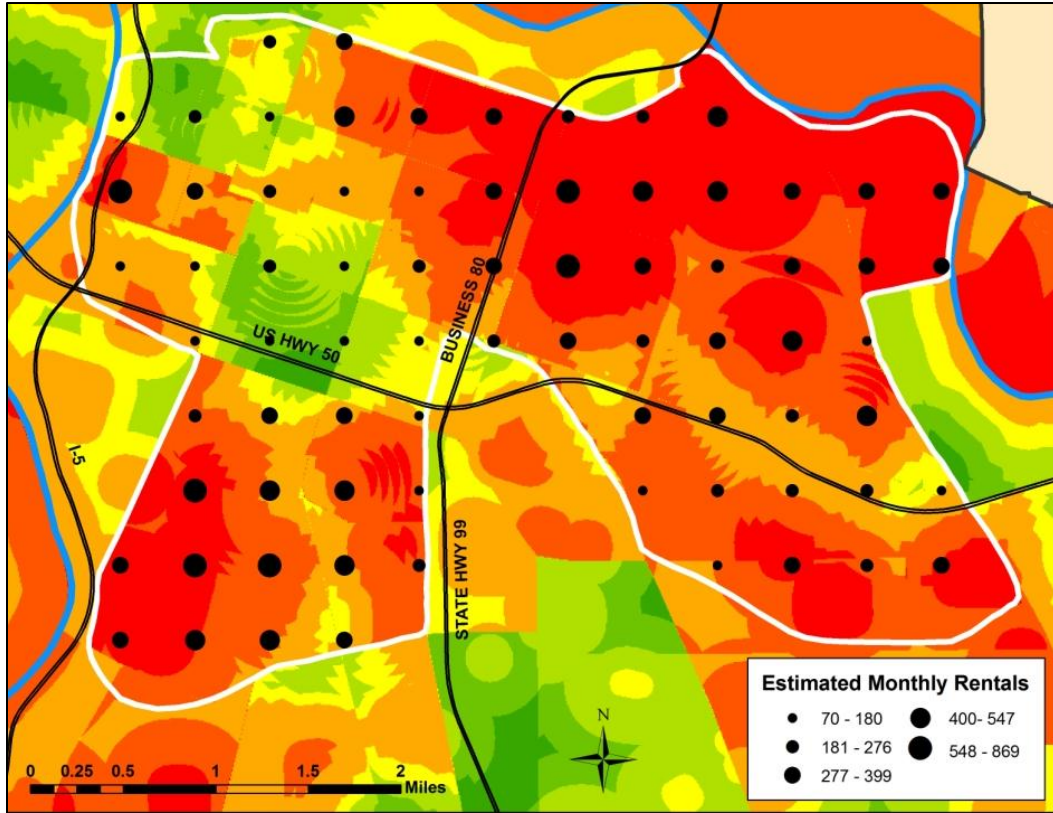
		Primary Service Area	Secondary Service Area	Combined Service Area, Total Rentals Only
Scenario 1	Total Rentals per Month (Confidence Interval)	23,722 (12,636 – 45,125)	3,142 (1,751 – 5,648)	26,864 (14,387 – 50,773)
	Average Per Station (Confidence Interval)	316 (168 – 602)	143 (80 – 257)	
	Minimum Station Value (Confidence Interval)	70 (35 – 140)	90 (44 – 181)	
	Maximum Station Value (Confidence Interval)	869 (492 – 1,537)	211 (120 – 371)	
Scenario 2	Total Rentals per Month (Confidence Interval)	25,124 (13,436 – 47,585)	3,142 (1,751 – 5,648)	28,266 (15,187 – 53,233)
	Average Per Station (Confidence Interval)	335 (179 – 634)	143 (80 – 257)	
	Minimum Station Value (Confidence Interval)	95 (45 – 176)	90 (44 – 181)	
	Maximum Station Value (Confidence Interval)	897 (498 – 1,888)	211 (120 – 371)	

14
 15 Depending on station placement, the Sacramento program can be expected to have between
 16 23,722 and 25,124 monthly rentals within the primary service area, with individual station values ranging
 17 from 70 to 897 rentals per month and averaging between 316 and 335 rentals per month. If the secondary
 18 service is incorporated, total monthly values can be expected to reach between 26,864 and 28,266 rentals.
 19 These figures are approximately on par with those observed for the Nice Ride program, which reported a
 20 system-wide total of 23,112 rentals during August 2010. As the Nice Ride rentals were recorded during
 21 August, the values in Table 5 should be considered as estimates for the months most conducive to cycling
 22 in Sacramento.

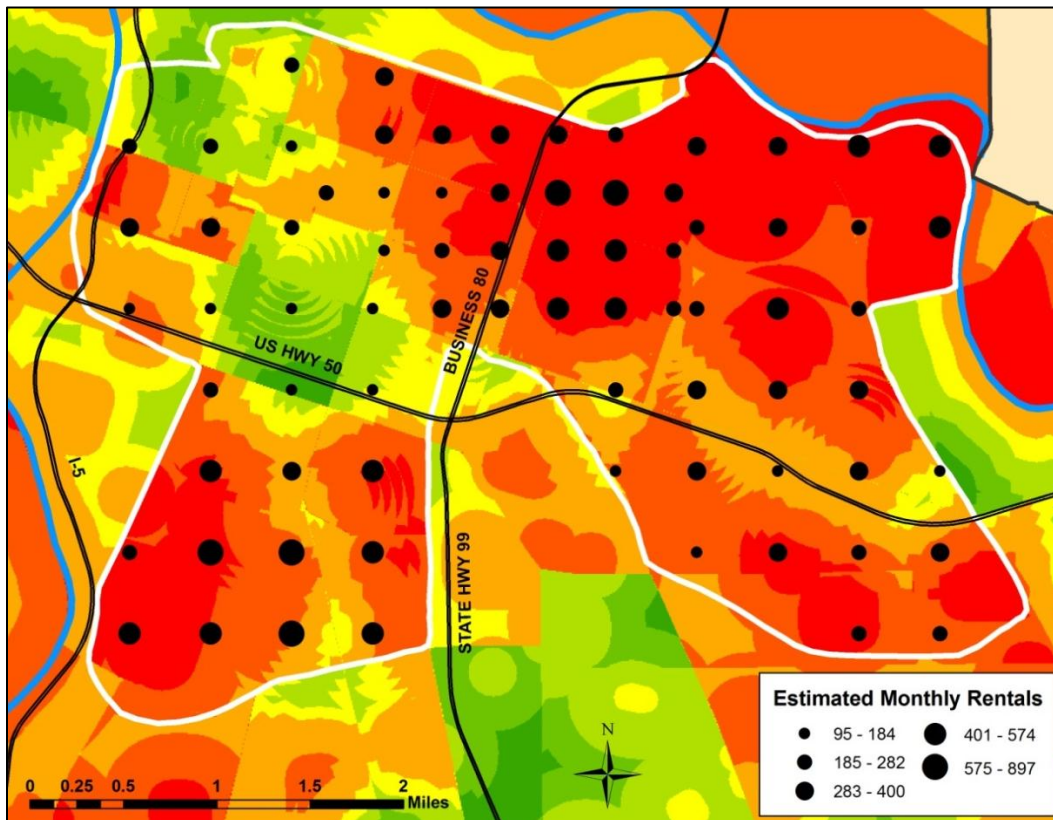
23 When empirical error is taken into account, the estimates range widely: from 14,387 to 53,233
 24 monthly rentals for the program as a whole. While it is possible that rentals will converge on the estimates
 25 around which the confidence intervals were constructed, this range demonstrates the importance of noting
 26 potential deviations from empirically estimated values.

27 Additionally, it should be noted that the Sacramento estimates are likely to be low due to the
 28 process of placing stations for this analysis. Although the delineation of service areas was driven by the
 29 results of the suitability analysis, the placement of stations *within* these areas resulted from a high-level
 30 process rather than consideration of micro-level characteristics. In reality, planners will benefit from local
 31 knowledge when determining the exact intersections and amenities at which stations should be located,
 32 thus achieving maximum ridership potential.

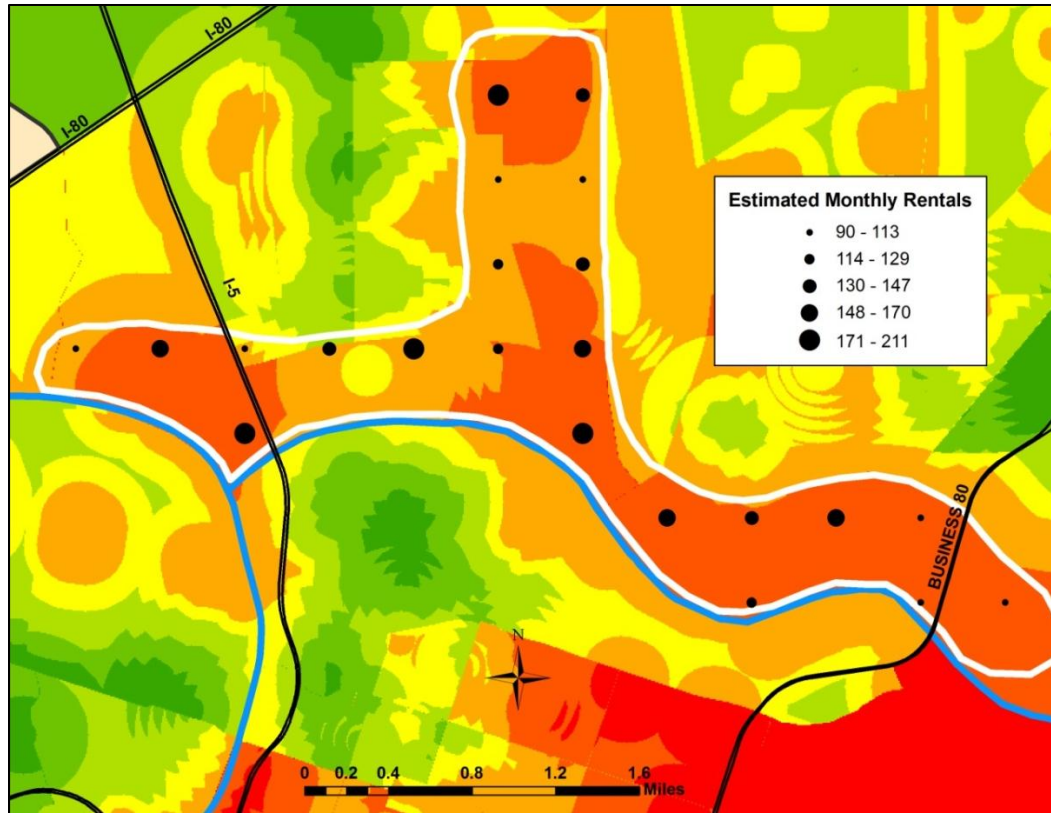
33 The spatial distribution of stations and estimates for Scenarios 1 and 2 (not accounting for
 34 confidence intervals) are displayed in Figures 3 through 5.



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2
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FIGURE 3 Estimated Rentals by Station in the Primary Service Area, Scenario 1 (Low)



4
5
FIGURE 4 Estimated Rentals by Station in the Primary Service Area, Scenario 2 (High)



1
2 **FIGURE 5 Estimated Rentals by Station in the Secondary Service Area, Both Scenarios**

3 **DISCUSSION**

4 Although the suitability and rental calculations in Sacramento were based on observed experiences in
5 Minneapolis, the results do not align entirely with theory. As shown in Figures 2 through 4, the
6 distribution of suitability and rentals, as calculated through the regression-based model, does not adhere to
7 the theory that bike-share use will be highest in the central business district and lower in outlying areas.

8 These results must be interpreted with caution given their origin in data estimated for another
9 city. The application of Minneapolis findings to the Sacramento context may be affected by two sources
10 of bias: out-of-range predictions and underlying differences between the two cities.

11 First, eleven independent variables in Sacramento have values that fall outside of the range of
12 values observed in Minneapolis. Because the preferred regression model was not calibrated using these
13 values, the application of the model to the Sacramento context is subject to bias that could play a role in
14 the unexpected results.

15 Second, the results must be considered in light of the underlying differences between Minneapolis
16 and Sacramento. Ten variables in the preferred regression model have notably different mean values in
17 Sacramento and Minneapolis. The density of population, employment (total and retail), high-income jobs,
18 and attractors is considerably lower in Sacramento, as are the values for three key transportation factors.
19 Particularly dramatic among the latter variables is the lower degree of transit intensity in Sacramento.
20 Alternatively, both median income and the proportion of households with low vehicle availability are
21 substantially higher in Sacramento. In addition to introducing potential bias, these comparisons have two
22 interesting implications for the results of the suitability analysis and rental projections:

- 23
- 24 • Although it is insignificant, the coefficient for *Transit Intensity* in the preferred regression suggests a
25 negative association between transit service and Nice Ride rentals. This relationship could indicate
26 that transit and bike-share are primarily competing rather than complementary modes in this city,
27 which is very well-served by the transit network. In Sacramento, however, transit service is
28 comparatively low: the average hypothetical station area in Scenario 2 is served by only 9 transit

1 vehicles during the morning peak hour, compared to a mean of 142 vehicles in Minneapolis. Given
 2 this relatively low level of bus and rail service in Sacramento, it is possible that the bike-share mode
 3 would not face significant competition from transit but would instead serve as an attractive alternative
 4 or complementary mode. Thus, both suitability and rentals may be higher in downtown Sacramento
 5 than predicted through the Minneapolis-based analysis.
 6

- 7 • Similarly, a negative coefficient was obtained for *Jobs* in the Minneapolis regression. This may be
 8 due to competition from alternative modes in very dense areas, as well as to the self-contained nature
 9 and physical presence of very large employment complexes. Given that job density is considerably
 10 lower in Sacramento, these conditions may not hold and both suitability and rentals may be higher in
 11 the downtown area than predicted based on the Nice Ride experience.
 12

13 Finally, the low rentals projected for the downtown area may result in part from underlying
 14 differences in urban structure and dynamics between the two cities. For instance, median income is
 15 relatively high in downtown Minneapolis compared to outlying areas, an observation that could explain
 16 the positive coefficient for *Income* in the preferred regression model. Alternatively, the Sacramento study
 17 area demonstrates the opposite pattern, with notably lower median incomes downtown than in peripheral
 18 areas. Given the positive effect applied to median income in the suitability analysis and rental projections,
 19 this spatial distribution provides a potential explanation for the low values estimated for downtown
 20 Sacramento.

21 These observations suggest a variety of potential explanations for the somewhat unexpected
 22 results obtained for Sacramento. Given these observations, the results of this analysis must be carefully
 23 considered in light of the underlying differences between Minneapolis and Sacramento for several key
 24 regression variables.
 25

26 **Lessons for Station Placement**

27 To understand the limitations of the preferred model and to derive lessons for station placement, an
 28 evaluation was conducted of Nice Ride stations for which monthly rentals were significantly under- or
 29 over-predicted by the model. Based on aerial imagery and a conversation with the Nice Ride Operations
 30 Director, these stations were analyzed to identify factors that could account for their departure from the
 31 estimated model. The results of this conversation are summarized below.
 32

- 33 • **Timing and visibility matter.** Stations that were established after the program officially began or
 34 that experienced low visibility tended to have actual rentals lower than those predicted by the model.
- 35 • **The *type* of retail establishments matters.** Areas offering unique and mixed retail establishments,
 36 including small businesses, should be considered as particularly suitable locations for bike-share
 37 stations. Actual rentals tended to be higher than predicted in these areas, suggesting that the preferred
 38 model does not adequately capture retail size and mix.
- 39 • **The *size and type* of employment destinations matter.** Large employers often function as self-
 40 contained entities and may create physical barriers that discourage travel between surrounding uses.
 41 Furthermore, the *mix* of employment appears to matter, as homogenous employment centers tended to
 42 be overestimated by the model. These observations could help to explain the negative regression
 43 coefficient obtained for *Jobs*, as very large employers with contained campuses may have skewed the
 44 measurement of this variable.
- 45 • **The *size* of a university campus matters.** Bike-share ridership on small, self-contained campuses
 46 may be lower than that on larger university campuses, where distances between destinations may be
 47 quite large. Major universities are also more likely to draw visitors from the community.
- 48 • **The regression model may not offer an adequate treatment of *transportation network factors*.**
 49 Several significantly underestimated Nice Ride stations were located near rail stops and/or
 50 considerable cycling amenities. Although *Distance to Rail* and *Bikeways* were insignificant in the
 51 preferred model, the error analysis suggests that they may be important factors in station placement.

- 1 • **The *network effects* between bike-share stations are important.** Although some stations recorded
2 lower-than-anticipated rentals due to their proximity to other popular stations, interaction with other
3 stations and integration into the larger system was crucial to the recorded success of others. Thus,
4 planners should strive to anticipate the complex ways in which stations will interact as a network,
5 including how station siting will affect considerations such as bicycle redistribution.
6

7 The analysis of stations with high error revealed a variety of factors that should be considered as planners
8 interpret the results of the preferred model and place stations throughout a program.
9

10 CONCLUSIONS AND RECOMMENDATIONS

11 This study established an analytical tool that can be used to plan for future bicycle sharing programs in
12 U.S. cities. Through an empirical approach that is grounded in the experiences of an existing U.S.
13 program, this process provides results that planners can use to outline appropriate service areas and
14 determine how many rentals—and thus how much revenue—can be expected. This feasibility approach is
15 particularly important given the currently limited research of the cost-effectiveness of bicycle sharing
16 programs.

17 The study also provides insight into the determinants of bike-share rentals in the U.S. context, an
18 important contribution to a body of research that has until now been limited primarily to European
19 observations. The results suggest that bike-share suitability is highly influenced by an area's income,
20 racial composition, job density, high-earnings job density, commute patterns, and proximity to rail
21 stations and parks. While past studies have emphasized traditional factors such as transportation
22 infrastructure and population density, this study suggests a variety of additional characteristics that should
23 be considered when determining the location and extent of new programs. Importantly, the findings
24 related to socioeconomic factors such as income and race must be carefully considered and used only to
25 *expand* service rather than to contract it. Additionally, these findings attest to the importance of outreach
26 efforts and fare structures that ensure equity and inclusiveness in service provision.

27 As programs continue to emerge, researchers should repeat this process for a variety of U.S. cities
28 to develop a refined understanding of the determinants of bike-share use. Through this investigation, a
29 robust set of strategies for promoting bike-share can be developed in support of enhanced environmental
30 and health outcomes for U.S. cities. This methodology should also be repeated as new programs are
31 planned in order to optimize location, predict revenues, and make the most of program investments. As
32 ridership data for more programs become available, researchers should select comparison cities with
33 similar demographic, spatial, and transportation dynamics in order to maximize the effectiveness of
34 decision-making.
35

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