2. Demand Analysis

Introduction

The objective of the demand analysis was to provide a quantitative evaluation of a bike-share system in Seattle. By incorporating best practices from recent bike-share feasibility studies in North America, our methods were designed to identify market areas where bike-sharing has the highest potential. The analysis also forecasts demand for bike-sharing in those areas.

The Demand Analysis has three sections:

- **Indicators** - This section provides background information and justification for the twelve indicators used to identify bike-share market areas.
- **Analytical Methods** - The Analytical Methods section describes the methodology used in our demand analysis, which consisted of a geographic information systems (GIS) analysis based on our indicators. This analysis identified geographic areas, which led to a recommendation of phased implementation. This in turn supported estimation of trip-level demand for a bike-share system in Seattle.
- **Results** - This section introduces our findings, including three proposed phases of bike-share implementation and their demand projections. Included is the Impacts of Climate and Culture section, which compares Seattle to peer European cities with bike-share systems.

Modeling Methods Review

During our literature review, we evaluated methodologies that have been used in European and North American cities with successfully implemented bike-share programs to find best practices in the industry. While the practice of assessing bike-share demand is relatively new and relevant data are scarce, some lessons learned were useful.

The first large-scale, third generation bike-share program in Lyon, France, determined that population and employment densities, along with compact station density, are critical for ensuring ease of access for customers. To meet its density criteria, Lyon's modeling consisted of laying a 300-meter grid over density maps to identify potential high-use areas. Planners then used the grid to appropriately space stations throughout the high-use area.

Planners in Paris, France, added indicators for retail-based and facility-based trips to Lyon's existing density indicators and developed a "cumulative-trip" demand for the entire city. Paris applied a similar 300-meter grid to identify varying trip thresholds that predicted levels of bike-share demand within each square. This resulted in three categories of demand—low, medium, and high—for which varying numbers of bicycles were supplied to meet the demand. However, Parisian planners significantly underestimated the number of bicycles needed by about 11,000 bicycles.

Montréal, Canada, estimated its bike-share demand by defining the service area on the basis of population density statistics similar to those found in Lyon. Once the service area had been determined, Montréal applied the density and ratio of bicycles used in the Lyon study. In addition to this rather basic approach, Montréal funded a market study to supplement its demand estimates and to produce pricing and revenue projections.

Representing what we think is the most advanced methodology to date for estimating bike-share demand, the Delaware Valley Regional Planning Commission (DVRPC), Philadelphia's metropolitan planning organization, used a much more thorough, data-rich, and fine-grained analysis. Its analysis had ten indicators and used a GIS-weighted sum raster analysis to identify two market area phases. Once the market areas had been determined, a sketch-planning method was developed to estimate trip-level demand for bike-sharing on the basis of the demand for existing modes and diversion rates observed from European systems.[21] This methodology benefited from combining local data with observed industry standards from successful European programs. It not only supported a fine-grained analysis with additional indicators representing transportation network and facility factors, but it also provided a flexible range of demand projections. We think this approach represents the best available science in the industry for determining bike-share feasibility. Our demand analysis relied on the methodology developed by the DVRPC.

Analysis Summary

Our demand analysis addressed two primary questions: 1) where in Seattle is bike-sharing most suitable, and 2) what are the anticipated demand levels within those areas? To determine where bike-sharing would be most successful, we used a weighted sum raster analysis in GIS to identify proposed phases for bike-share implementation. Using these proposed implementation areas, we applied European diversion rates to local trip-level data.

In summary, our demand analysis utilized the following steps:

1. Identify 12 indicators favorable to bike-share use.
2. Convert the indicators into GIS raster data to ensure "apples to apples" comparison.
3. Aggregate the indicators into a composite bike-share score by using a weighted sum raster analysis.
4. Map the composite score data to identify contiguous, high-scoring areas and draw boundaries to represent proposed bike-share implementation areas.
5. Calculate the demand for existing transportation modes within the

21 JzTI and Bonnette Consulting with the Delaware Valley Regional Planning Commission. (2010). Philadelphia Bikeshare Concept Study.

proposed implementation phases.

6. Apply diversion rates to existing Seattle trips to determine demand for bike-share.

7. Apply industry standards to estimate the number of bicycles and stations needed.

Indicators

Our indicators measured the suitability of an area for supporting bike-sharing. Each indicator related to particular characteristics. Our twelve indicators are listed in Table 2. Ten were used in the Philadelphia analysis, and two were added to capture unique features of Seattle. Topography was not included in the Philadelphia study but was included in this analysis. Knowing that flatter terrain is more favorable to cycling in general, the highly variable topography in Seattle is expected to affect bike-share use and is an appropriate indicator for a Seattle study. The Commute Trip reduction variable was also another variable relevant to bike-share ridership that was not present in the Philadelphia analysis. The indicators are discussed in further detail in the next section.

Table 2: Indicators

	Indicator	Scale	Metric	Buffer	Weight	Data Source
	Population Density	TAZ	Population per acre	n/a	1	2008 PSRC Population and Housing Estimates
	Non-Institutionalized Group Quarter Population Density	TAZ	Group quarter population per acre	n/a	0.5	2008 PSRC Population and Housing Estimates
	Job Density	TAZ	Jobs per acre	n/a	1	2008 PSRC Covered Employment Estimates
	Retail Job Density	TAZ	Retail jobs per acre	n/a	1	2008 PSRC Covered Employment Estimates
	Commute Trip Reduction (CTR) Companies	10 meter cell size	Point density	n/a	1	King County Metro
	Tourist Attractions	10 meter cell size	Point density	1000 meters	1	Seattle Department of Planning and Development
	Parks/Recreation Areas	10 meter cell size	Proximity distance	1000 meters	0.5	WAGDA (Seattle Parks Layer)
	Topography	10 meter cell size	Slope angle	n/a	1	WAGDA (WA Digital Elevation Model)
	Regional Transit Stations	10 meter cell size	Proximity distance	1000 meters	1	WAGDA (ST Link. ST Sounder, Amtrak, Ferry, ST Express)
	Bicycle Friendly Streets (including streets with bicycle lanes)	10 meter cell size	Proximity distance	1000 meters	1	WAGDA (SDOT bicycle layer)
	Streets with Bicycle Lanes	10 meter cell size	Proximity distance	1000 meters	1	WAGDA (SDOT bicycle layer)
	Local Transit Stops	10 meter cell size	Point density	1000 meters	1	WAGDA (Metro stops, Street Car)

Residential Population Density

Residential density supports bike-share demand by providing a pool of potential users. Even the simplest bike-share analyses have included this indicator. Higher density improves accessibility, which reduces travel distances and makes non-motorized travel more feasible.[22]

Residential density also indicates the number of off-peak trips that might be taken. In particular, personal business and social/recreational trips can be estimated on the basis of residential population density. Off-peak use increases demand for a bike-share system through the day, with the added benefit of helping to balance bicycle inventories across the city.

Higher population densities also correlate with less automobile dependence and higher use of alternative transportation choices.[23]

Non-Institutionalized Group Quarter Population Density (University Housing)

University housing was included with general residential population density, but we also chose to include it as a second factor to increase its weight as an indicator. Student populations are a likely market for bike-sharing because of their average age and large transit mode share. In addition, the structure is in place for education about bike-share and transportation choices because students regularly use the same spaces, and colleges already have systems in place to market programs and share information. These marketing systems are similar to Commute Trip Reduction companies, discussed in further detail below.

This indicator captured housing at the University of Washington, Seattle Pacific University, and Seattle University. Any group housing, whether on campus or not, was also included. It did not include institutionalized or incarcerated housing.

While college students' ages vary, 76 percent of students are between 18 and 29.[24] According to surveys, university students fit the profile of bike-share users, who are most likely to be "18-34 years in age [with a] high level of education."[25] This makes university housing density a good indicator because university students offer a great market for new bike-share users.

Another factor is that at Seattle's universities, transit mode-share is high, meaning that a large number of the population ends their trips with the last mile not accommodated by transit. Bike-sharing offers a transportation choice for these

22 Litman, T., & Steele, R. (2008). Land Use Impacts on Transport: How Land Use Factors Affect Travel Behavior. Vancouver, British Columbia: Victoria Transport Policy Institute.

23 Ibid.

24 U.S. Census Bureau. (2008, October). Social and Economic Characteristics of Students: October 2008. Retrieved February 3, 2010, from School Enrollment: http://www.census.gov/population/www/socdemo/school/cps2008.html

25 CityRyde. (2009). CityRyde Bike-sharing Informational Webinar. Philadelphia.

students. In fact, at the University of Washington, the Climate Action Plan reported that 79 percent of students choose alternative transportation (see Table 3). These students are potential users of bike-share.

At the University of Washington, the Climate Action Plan reported that 79 percent of students choose alternate transportation. These students are potential users of bike-share. Bike-share can serve the 60% of student population who live within five miles but are not already biking or walking.

Table 3: Mode Share at University of Washington Seattle Campus[26]

Mode	Percentage
Single occupancy vehicle	21
Ride share	5
Transit	39
Walk	25
Bicycle	8

In addition, institutional commitment at the universities to alternative transportation should help generate bike-share riders. One of the strategies in the University of Washington's Climate Action Plan is to support bicycling and walking. "Almost 60 percent of the Seattle campus population lives within five miles of campus, and today there are many people that bike or walk occasionally, but do not make those options their primary commute choices."[27] Bike-sharing can potentially support this strategy by reaching the 60 percent of the student population who live within five miles but are not already biking or walking.

Finally, universities are frequently surrounded by mixed-use development, as well as pedestrian and bicycle friendly environments that are conducive to bike-share usage.

According to surveys, university students fit the profile of bike-share users, who are most likely to be "18-34 years in age [with a] high level of education."

Because these populations were also counted within the Population Density indicator, accounting for them with group housing would count them a second time. However, we thought that double-counting students in dormitories would give too large a weighting to these populations. Therefore, we applied a half weighting to this indicator.

Job Density

At a basic level, job density measurements indicate where people are during the day. As with most transportation infrastructure, higher density yields greater efficiency in service provision.

26 University of Washington. (2009). Climate Action Plan. Retrieved February 3, 2010, from http://f2.washington.edu/oess/sites/default/files/file/UW%20Climate%20Action%20Plan%20091509.pdf
27 Ibid.

Employment density measures the intensity of morning commute attractors and midday trip origins.[28] Previous research has indicated that employment density is one of the primary predictors of bicycle use. For example, Frank and Pivo found that job density has a greater impact on commute mode choice than residential density, particularly when workplace density reaches 50 to 75 employees per acre.[29]

Retail Job Density

Retail density was included in the demand analysis because of its function as a trip attractor.

In addition to being a way for commuters to travel "the last mile" from their transit endpoint to their employer's door, bike-sharing has been envisioned as a way for users to complete their errands before, during, and after the workday. Therefore, the presence of dense retail should provide trip destinations for bike-share users who live or work nearby.

When analyzed in conjunction with population density and general employment density, this indicator helps show land-use mixing, which "tends to reduce travel distances, and allows more trips to be made by walking and cycling…Employees who work in mixed-use commercial areas are more likely to commute by alternative modes."[30] This was confirmed by Cervero, who found that "having appreciable retail/service activities within a 1-mile radius of a person's origin generally encouraged that person to bicycle."[31] Cervero also reported that "for every 1,000 retail workers within a half mile of a person's home, the likelihood a person will bike or walk to non-work activities goes up by 7 percent."[32]

However, not all retail is created equal; some may generate a greater number of trips than others. Using the number of establishments or square footage may over-weight large but low-intensity uses such as furniture warehouse outlets; therefore, we used the number of retail jobs to measure intensity of retail use.[33]

Frank and Pivo found that job density has a greater impact on commute mode choice than residential density, particularly when workplace density reaches 50 to 75 employees per acre.

28 Tyler Benson, "Public Use Bike Share Feasibility Study: Volume Two: Demand Analysis," 2009, p. 2.18.
29 Benson, p. 2.103.
30 Benson, p. 2.104.
31 Ibid.
32 Arrington & Cervero, as quoted in Benson, p. 2.105.
33 "Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?" Journal of the American Planning Association, 2008, p.478

Commute Trip Reduction

Commute Trip Reduction (CTR) is a law that mandates larger employers to manage the transportation demands of their employees. Businesses with more than 100 employees in any one location are required to implement a CTR plan. The City of Seattle works with over 250 employers with a total of over 55,000 employees, a number that includes the City itself as a major employer. Participating companies must provide an Employee Transportation Coordinator for the program, develop a plan to reduce drive-alone commute trips, submit the plan and an employee survey every two years, and exercise good faith efforts to reduce drive-alone commute trips.[34] This indicator was not included in the Philadelphia feasibility study but was added as an indicator here as a beneficial feature in Seattle.

> In addition to being a way for commuters to travel “the last mile” from their transit endpoint to their employer’s door, bike-sharing has been envisioned as a way for users to complete their errands before, during, and after the workday.

Transportation demand management programs like CTR use incentives to encourage use of alternative transportation.[35] The programs do not require employees to change habits, but they do create the support structure to make those choices easier.

This CTR program facilitates relationships between SDOT and major employers and can provide a communication point for implementing bike-sharing. Employee Transportation Coordinators have training and interest in reducing single occupancy vehicle (SOV) trips and are a good resource. In addition, the survey process provides a no-cost tool for additional measurement of bike-share usage, at least for these participating employers. This program can help support true involvement from large employers in the city.

The bike-share program and CTR can be mutually supportive; studies show that comprehensive CTR programs can reduce peak-period automobile trips by 5 to 20 percent, and even more when accompanied by transit improvements.[36] Seattle’s goals for the downtown neighborhoods are to increase non-SOV trips by 14 percent. Bike-sharing and additional transit improvements can help meet or exceed that goal. See Appendix C for mode share targets from the Commute Trip Reduction Plan.

CTR paired with bike-sharing can reach employees who would not have chosen alternative transportation before. Employees sometimes choose to drive to work just to have a car to run errands at breaks. Bike-sharing can help provide options for these employees.

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34 City of Seattle. (2009). Commute Trip Reduction Basics. Retrieved January 22, 2010, from City of Seattle: http://www.seattle.gov/waytogo/commute.htm

35 Victoria Transport Policy Institute. (2010, January 25). Commute Trip Reduction. Retrieved January 30, 2010, from TDM Encyclopedia: http://www.vtpi.org/tdm/tdm9.htm

36 Ibid.

Employers with less than 100 employees are not covered by CTR requirements. The Downtown Seattle Association and the City of Seattle work together to reach out to these employers and coordinate alternative transportation choices.[37] This coordination can help bring education about bike-sharing to smaller companies that are not covered by CTR.

CTR employers were selected as an indicator because of the systems in place to encourage bike-share among employees. The employment density of these companies was also counted under the job density indicator. Including them in a separate category gave them extra weight, which was warranted by the CTR planning and implementation in place.

Tourist Attractions

Tourist attractions are destinations for bike-share users. The degree to which the presence of a tourist attraction affects bike-share ridership will vary on the basis of whether the business model allows short-term memberships.

The Vélib' program in Paris was specifically designed and priced to support tourist travel. It allows purchase of daily and weekly memberships in addition to annual memberships. Daily memberships cost 1 Euro (approximately $1.40, or 3 percent of the cost of an annual membership) and weekly memberships cost 5 Euros (approximately $6.90, or 17 percent of an annual pass)—in addition to the hourly rate. This allows tourists to purchase short-term memberships at kiosks with their credit cards. Day passes have been relatively popular; in its first year Vélib' generated 198,913 annual subscriptions and 3,683,174 one-day subscriptions.[38] Programs being designed in Philadelphia and Minneapolis are also taking this approach.[39]

In contrast, the Bicing program in Barcelona does not offer memberships shorter than one week, and these, like the annual memberships, are restricted to residents of Spain. This decision was made to avoid draining business from private tourist-oriented bicycle rental companies. Current demand from annual users already exceeds capacity without the inclusion of tourists.[40]

Transportation demand management programs like CTR use incentives to encourage use of alternative transportation. The programs do not require employees to change habits, but they do create the support structure to make those choices easier.

37 City of Seattle, Commute Trip Reduction Basics, 2009, http://www.seattle.gov/waytogo/commute.htm (accessed January 22, 2010).
38 Nice Ride, Twin Cities Bike Share, Non-Profit Business Plan (Minneapolis: City of Minneapolis; Community Planning and Economic Development Department, 2008).
39 Ibid.
40 Ibid.

This analysis assumed that a Seattle program would include membership options for tourists. Many tourist attractions are focused in the downtown area. Tourists using bike-share could access these attractions without contributing to the congestion and parking pressures in the downtown area. This would be an added benefit of increased mode share choices.

In addition to enticing short-term members, the tourist attractions included in this study could also generate trips for Seattle resident bike-share users, as community amenities such as museums and libraries were included in the tourist attraction category.

Parks

Parks are a bike-friendly land use; cyclists are comfortable biking in parks. Parks serve as a destination for both residents and tourists in Seattle. However, we used a half weight for parks because bike-sharing will likely serve more work, shopping, and social trips than recreational trips. In fact, experiences in other cities have indicated that modern bike-share systems are not used for recreational purposes. In Barcelona, 57 percent of Bicing users made trips for work reasons.[41] Data from Washington, D.C., showed similar results: SmartBike DC riders used bike-share primarily for social purposes: 26.2 percent; work: 22.2 percent; and shopping: 20.0 percent.[42] A 2007 survey of Paris users showed that 67 percent of weekday riders used bike-share for work purposes.[43] This emphasis on non-recreational riding means that bike-sharing is less likely to be used inside parks, though parks do serve as possible destinations.

One of the primary goals of a bike-share program is to encourage non-motorized transportation and increased bicycle use. Although categorizing parks as bike-share destinations was consistent, our analysis excluded the idea of placing stations within parks, as this would change the focus of bike-sharing to a recreational activity.

Topography

Though the available literature on the effect that urban topography has on rates of cycling is limited, there are a few main points worth noting that heavily influenced our use of topography as an indicator. A recent study on the determinants of bicycle mode share for journey to work trips found that hilliness is a very significant indicator of the proportion of people that cycle to work.[44] Furthermore, ridership is elastic in response to hills, with a 10 percent increase in the degree of hilliness linked to a 10 to 15 percent reduction in the proportion of people cycling to work.[45]

41 Tyler Benson, "Public Use Bike Share Feasibility Study: Volume Two: Demand Analysis," 2009, p. 2.77

42 Benson, p. 2.78

43 http://www.nxtbook.fr/newpress/Mairie-de-paris-direction-voirie-deplacements/Paris_transport_and_travel_2007_report/index.php#/20

44 Parkin, J., Wardman, M., & Page, M. (2008). Estimation of the determinants of bicycle mode share for the journey to work using census data. Transportation , 35, 93-109.

45 Parkin, J., Ryley, T. J., & Jones, T. J. (2007). Barriers to Cycling: An Exploration of Quantitative Analysis. In D. Horton, P. Rosen, & P. Cox (Eds.), Cycling and Society (pp. 67-82). Burlington, Vermont: Ashgate Publishing Company.

It is clear from a review of the literature that steep hills can be a major impediment to cycling. However, this is especially true in the case of bike-sharing because the bicycles are typically heavier than average and utilize fewer gears. In addition, a higher proportion of novice cyclists or occasional riders are likely to use the system in comparison to regular cyclists or bicycle commuters in the city. Therefore, topography should be considered very carefully when the potential demand of a program and location of implementation are analyzed.

Transit Network

Regional and local transit stops have been selected as an indicator because they provide a ready population of people traveling to destinations. Bike-sharing can provide on-demand "last mile" transportation for these transit customers, creating a seamless transportation experience. It is likely that bike-sharing will become a part of the variety of choices available to commuters. In other cities, once bike-sharing has been implemented, many bike-share trips are trips diverted from transit. However, research has shown that these are likely just segments of a trip partially completed on transit, where bike-share serves as one more travel choice. In Lyon, more than 50 percent of bike-share trips were diverted from transit, but there was very little reduction in the number of transit passes purchased.[46] These bike-share users "diverted" from transit were likely still using transit and then using bike-share to complete the last mile of their journey in a more convenient manner.

New users may be attracted by the increased travel options that bike-sharing offers, and existing transit users may be retained when they can quickly move between transit and a bicycle.

The transit network category was divided into separate indicators: regional transit and local transit.

Regional Transit

Regional transit was defined as stations or stops serving Amtrak, Washington State Ferries, King County Ferries, Sound Transit Link light rail, Sound Transit Commuter Rail, Sound Transit Express Bus Service, and other transit that crosses city lines. People arriving in Seattle via regional transit are ideal customers for bike-sharing. They are heading to a destination within Seattle but likely have an additional segment to complete, the "last mile." Bike-sharing can provide a quick and convenient mode to get them there.

Local Transit

Local transit is a separate indicator because trips made by King County Metro local bus service and City of Seattle South Lake Union Streetcar are typically shorter than trips made by regional transit. Although King County Metro also provides regional trips, it is the main provider of local transit.

46 Tyler Benson, "Public Use Bike Share Feasibility Study: Volume Two: Demand Analysis," 2009, 2.71.

Some local bus trips have the potential to be highly complemented by bike-sharing on both the origin and destination sides of the trip. Studies have shown that the wait time between buses or during transfers is perceived to be two to three times longer than the actual time. Any reduction in perceived wait times will help attract riders.[47] Thus, new users may be attracted by the increased travel options that bike-sharing offers, and existing transit users may be retained when they can quickly move between transit and a bicycle. In rare cases, local transit trips may be replaced entirely by bike-sharing if the trip is short enough.

Bicycle Infrastructure

Several studies in the United States have found that the presence of bicycle lanes and paths is correlated with higher rates of bicycling or willingness to cycle. Few studies, however, provide data on what specific types of bicycle infrastructure (bicycle lanes, off-street trails, shared-lane markings) will be most effective at encouraging bicycle commuting among the general population. Indeed, most large sample surveys do not include questions about routes or facility preferences.

Several simple, stated-preference studies have found that people prefer bicycle paths and lanes or indicate that having such infrastructure would encourage them to bicycle more.[48] In addition, a national survey found that while frequent bicyclists preferred bicycle lanes rather than recreational paths, infrequent bicyclists were more likely to want more bicycle paths rather than lanes.[49]

Proximity to "Bicycle-Friendly Streets," Including Streets with Bicycle Lanes

A recent study in Portland, Oregon, documented the travel patterns of 166 cyclists for one week by using GPS technology. The researcher found that about half of all the miles of bicycle travel recorded by the GPS units occurred on roads with bicycle lanes, paths, or bicycle boulevards[50]—even though these facilities made up only about 8 percent of the Portland street network available to cyclists. For our purposes, these facilities can be classified as "bicycle friendly streets."

Proximity to Streets with Bicycle Lanes

Of the 52 percent of bicycle travel that occurred on "bicycle friendly streets," over half of those miles traveled took place on streets with defined bicycle lanes.[51]

The conclusions of the Portland study included the following: a supportive bicycle environment appears necessary to encourage bicycling for everyday travel; a network of different types of infrastructure appears necessary to attract new people to bicycling; and the areas where the highest levels of bicycling occur also have a well-connected street grid and mix of

47 Institute of Transportation Engineers. (1997). A Toolbox for alleviating traffic congestion and enhancing mobility.
48 Dill, J. (2009). Bicycling for Transportation and Health: The Role of Infrastructure. Journal of Public Health Policy , 30 (S1), S95-S110.
49 Bureau of Transportation Statistics. (2004). How Bike Paths and Lanes Make a Difference. Washington, D.C.: Bureau of Transportation Statistics.
50 Dill, J. (2009). Bicycling for Transportation and Health: The Role of Infrastructure. Journal of Public Health Policy , 30 (S1), S95-S110.
51 Ibid.

land uses.[52]

By taking into consideration the proximity to “bicycle friendly streets” (including streets with bicycle lanes), as well as the proximity to streets with actual bicycle lanes, we essentially “double-counted,” or weighted more heavily, the presence of on-street bicycle infrastructure in our analysis. This was done intentionally to take into account the impact of on-street bicycle infrastructure on rates of cycling, as noted in the literature on the subject.

Analytical Method

This effort addressed two primary questions: 1) where in Seattle is bike-sharing most suitable, and 2) what are the anticipated demand levels within those areas? Both of these questions were resolved by using a methodology adapted from the efforts of Krykewycz et al. from the DVRPC.[53]

Market Area Identification

The first step in this analysis was the development of the twelve demand indicators. Each indicator was assigned a weight to account for the relative influence it would have on measuring bike-share potential. Nearly all indicators were assigned a weight of 1.0, except the Non-institutionalized Group Quarter Population Density (NIGQPD) and Parks and Recreation metrics, which were given weightings of 0.5. The assumption that each indicator, with the exception of the two lower weighted indicators, would have a relatively equal effect on bike-sharing was based on our literature review and a desire to simplify the evaluation.

Each of the twelve indicators was evaluated for the entire City of Seattle by using geographic information systems (GIS) analysis. In a process known as raster analysis, an analysis was completed by gridding the city in 10-meter-square cells and assessing each cell for the strength of each indicator. In some cases (illustrated in Figure 2), data were only available at a more aggregated transportation analysis zone (TAZ) level. To create consistency, the TAZ level data were converted to the 10-meter-square cell resolution by applying the measurement to each cell within the TAZ.

Using GIS, we applied a variety of raster calculations, as indicated by the Scale and Metric attributes of our indicators (see Figure 2). After the raster file had been produced for each indicator in GIS, the distribution of scores was reclassified into a 10-point scale by using the quantile method.[54] For each indicator, the end product was a raster layer with each cell scored on a scale from 1 to 10. Appendix A displays the raster maps for each indicator; the darkest color and highest score always represent the cells deemed most suitable for bike-sharing, whereas the

52 Dill, J. (2009). Bicycling for Transportation and Health: The Role of Infrastructure. Journal of Public Health Policy , 30 (S1), S95-S110.

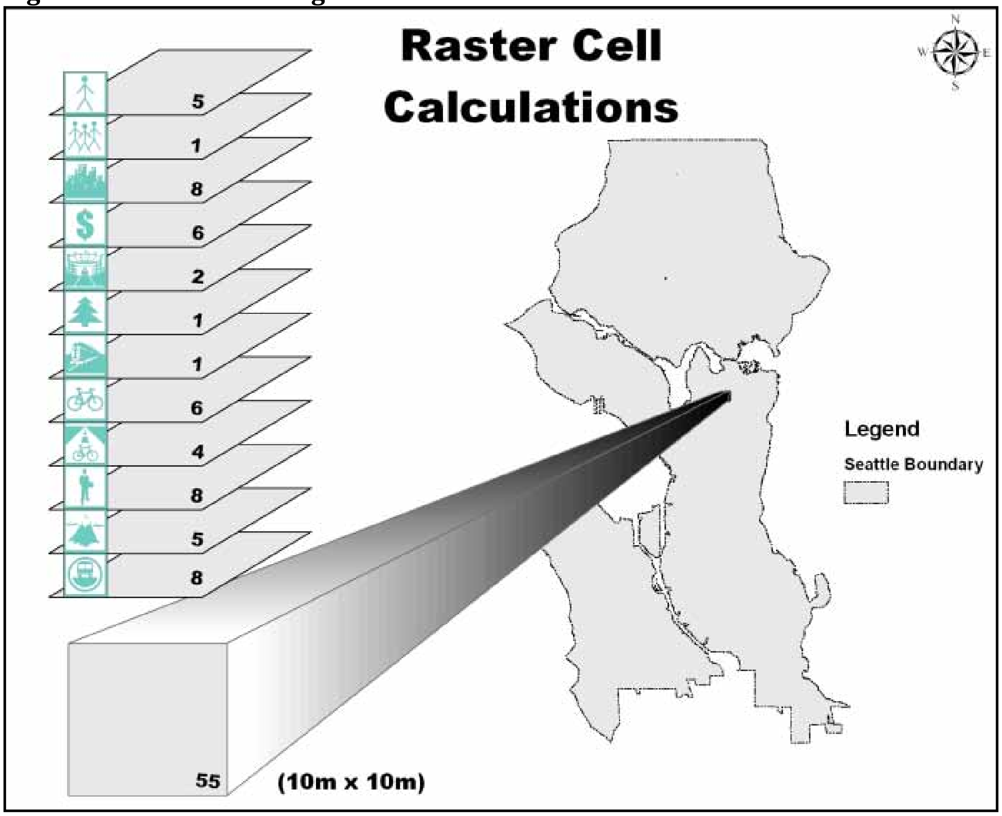
53 JzTI and Bonnette Consulting, *Philadelphia Bikeshare Concept Study*, (Philadelphia: Delaware Valley Regional Planning Commission, 2010).

54 In the quantile method, each classification has the same number of original measurements.

lightest, lowest-scoring cells are least suitable.

The individual raster files were combined by applying the weights and summing the score for each indicator. This process is known as a weighted sum raster analysis. The result was a raster map of Seattle with a composite bike-share score, with cell scores ranging from 11 to 110. Again, the higher numbers indicate more suitability for bike-sharing. The summation process is demonstrated for a hypothetical cell in Figure 2.

Figure 2: Theoretical Weighted Sum Raster Calculation



The final step for our analysis was reclassification of the raw raster summation into six bins using the geometrical interval classification[55] method, maintaining the 10 meter square resolution, and using higher numbers to indicate greater favorability. Maps of both the raw raster data and the reclassified data can be found in Appendix A of this document (Indicator Maps, Figures 11 to 22; Seattle Weighted Sum Raster Analysis, Figure 23; Seattle Weighted Sum Raster Analysis Reclassified to Six Levels, Figure 24; and Proposed Seattle Bike-Share Implementation Phases with Weighted Raster Analysis, Figure 25). We refer to cells in the reclassified map as being of Level 1 through Level 6, corresponding to their score.

Reclassification of the cells generated a data set that could be analyzed to assign proposed phased implementation areas for bike-share. This analysis supported drawing geographic

55 According to ArcGIS documentation, the method of geometrical interval classification creates class ranges with three properties: the squared sum of differences between the values in a class and the average value of the class is minimized for all classes; each class has approximately the same number of values or observations; changes between the range of each interval are approximately consistent. The coefficient or rate by which the interval changes may inverse once across all ranges.

borders for three proposed phases of implementation. Explained in further detail in the next section, regions with the greatest concentration of the Level 6 and 5 cells correspond to the best market area(s).

Demand Estimates

Upon completion of the market analysis, the proposed implementation areas were evaluated with a sketch-planning method to determine their likely demand for bike-share. This evaluation again relies on the work of Krykewycz et al., who used survey data from three existing bike-share programs in Europe (Lyon, Paris, and Barcelona) to indicate the relative attractiveness of bike-share to the users of various modes. Unfortunately, at the time of this study there were no comprehensive bike-share systems in North America with available data. Using the existing ridership of those modes, and the modal diversion rates, approximate numbers of bike-share trips are estimated. Table 4 illustrates the modal diversion rates developed by Krykewycz et al. that will be used in this analysis.[56]

Table 4: Bike-Share Modal Diversion Rates

	Diversion Rates		
	Low	Med	High
Car	0.06%	0.14%	0.18%
Bus	1.40%	3.80%	4.60%
Bike	1.80%	2.60%	3.40%
Walk	0.48%	0.56%	0.64%
New Trips	1.10%	2.20%	4.40%

Once identified, the diversion rates were applied to Seattle travel data. Seattle travel data was provided by the PSRC Travel Demand Model,[57] representing trip production and trip attraction characteristics at the TAZ level from 2006 base year data. For purposes of this study, the number of trips for each mode originating and terminating in each TAZ were summed and divided by two in order to avoid double counting. TAZ boundaries were overlaid on the proposed implementation areas identified during the demand analysis. In this manner we had access to the trip-level data necessary, when combined with diversion rates, to estimate bike-share trips for each TAZ. We then aggregated trip counts by mode for all TAZs in the implementation area.

56 Krykewycz et al. note that several assumptions were made in calculating the European diversion rates. Given, original mode share data for the European cities was only available at the metropolitan scale, simple factor was necessary to estimate mode share for the bike-share implementation area. Accordingly, their belief is that auto-mode share is likely to be over-estimated while other modes are likely to be under-estimated.

57 Puget Sound Regional Council Travel Demand Model, 2006 Daily Trips – Productions and Attractions aggregated to TAZ level. Provided by Chris Overby on 2/12/2010.

Transit Diversion Discussion

As Table 4 indicates, the majority of bike-share trips are being diverted from public transit. Although this shift from public transit might seem like a problem, especially for transit providers, the origin and relevance of this statistic should be further explored. Philadelphia's bike-share study notes that European public transit systems experience more peak-period 'crush-loading' than American systems. This would indicate a "higher initial mode-share burden and greater impetus for travelers to seek a more comfortable alternative."[58] The Philadelphia authors also state that the "survey results are not clear as to whether the cited bike-share trips had replaced all or just part of a transit trip, which would have different implications. An example of the latter case would be someone using bike-share rather than the bus to get to a train station, then resuming the journey on public transport."[59] In the public bike system in Lyon, France, up to 50 percent of bike-share trips were shifted from public transit, but "there was very little impact on the number of transit passes purchased, suggesting that public bike usage becomes part of an individual's array of transportation mode choices."[60] It is our conclusion that upon further review, the high diversion rate from public transit is not a drawback, but an opportunity to grow ridership by providing additional transportation alternatives.

Results

As described in Analytical Methods, we divided the City of Seattle into 10-meter-square cells to identify a proposed implementation area. Each square was evaluated on the basis of each bike-share indicator discussed in the Demand Indicators section. For example, cells with little to no difference in elevation within the cell bounds receive a high score for the *Topography* indicator; cells at a great distance from Metro bus and streetcar stops receive a low score for the *Local Transit Stops* indicator. We chose this method for its ability, at a granular level, to delineate areas of probable success.

In recommending potential implementation areas, it is assumed that a contiguous network that minimizes distance between stations is a critical characteristic of successful bike-share systems. A square-shaped implementation area is preferable when compared to a long, thin rectangle. This means that having a large number of contiguous Level 5 or 6 cells as well as maintaining a square-like shape were important factors in identifying the recommended implementation area boundaries.

Based on our analysis and these considerations, we are recommending a three-phase implementation strategy. Following successful implementation of Phase 1, Phases 2 and 3 can be brought on-line as the program grows and resources become available.

Implementation Phases

The Proposed Seattle Bike-Share Implementation Phases map in Figure 3 displays the three proposed implementation phases identified from our GIS analysis. The map generally

58 Philadelphia Bikeshare Concept Study, 2010, pg. 28.
59 Ibid.
60 Quay Communications Inc, V2, 2008, 16

shows Seattle's downtown and surrounding neighborhood areas scoring strongly as a candidate area for bike-share. Accordingly, we recommend this downtown area as the implementation area for Phase 1, depicted by the green shaded area. It is approximately four square miles, fairly symmetric with respect to height and width, and engenders a network in which stations would be evenly distributed. Reviewing the individual indicator maps, Appendix A, the downtown scores very strongly on five of the twelve indicators: *Commute Trip Reduction Companies*; *Tourist Attractions*; *Regional Transit*; *Streets with Bicycle Lanes*; *Local Transit Stops*, and strongly on four additional indicators: *Population Density*; *Job Density*; *Retail Job Density*; *Bicycle Friendly Streets*.

The proposed Phase 1 area is almost entirely composed of Level 6 cells. Furthermore, we know that the large pocket of Level 5 cells within the Phase 1 area is the Seattle Center, which scores lower for a lack of job, population, transit, or bicycle facility densities but is otherwise a very strong draw for residents and tourists alike. Although we acknowledge this is a large island of lower scoring cells, we believe that the presence of the Seattle Center is actually a partial reason that the surrounding cells score high. Given this fact, we believe it is important to include the Seattle Center in the proposed Phase 1 implementation area.

Despite the large number of Level 6 cells in the University District (UD), we did not include it in Phase 1—although this might be an issue worth exploring in greater detail. Note that the presence of the University of Washington (UW) and Children's Hospital in the UD could benefit a bike-share program. The UW has a strong history of supporting transportation alternatives, such as its UPass program. The UW also has a high potential to generate bike-share ridership, with 60 percent of its students and employees who don't already walk or bike living within 5 miles of campus. Furthermore, Sound Transit's LINK Light Rail line will be expanded to the UD in 2016, which will support connections with regional transit in the future. Finally, while Children's Hospital is not contained within the proposed implementation area, its previously stated interest in a bike-share program and planned facility expansion may ultimately affect whether this area is included.

However, although the UD has benefits to offer a bike-share program, it is approximately 2 miles from the downtown area, with varied topography and poor bicycle infrastructure in between, which could discourage bike-share trips between the downtown and the UD. Implementation in both areas, with or without intermediate stations, would create a disjointed network, increasing implementation risk without adding the benefits of a larger, contiguous network. A disjointed bike-share implementation area has not been observed in other bike-share programs in Europe or North America, so we believe that the risk would be too high for initial implementation.

For the proposed Phase 2 area we recommend a substantial increase in the network, adding approximately 14 square miles, including the UD. Along with the UD, the goal of Phase 2 is to expand to Level 5 cells. Doing so, while maintaining a dense, contiguous network, will require the inclusion of areas between these centers that scored lower than Level 5 or 6. These exceptions will be made in a desire to reduce user uncertainty about entering and exiting the network.

Finally, for proposed Phase 3, we propose expanding the implementation area to include outlying areas in North, Southeast and West Seattle. As seen in Figure 5, these centers lack a strong connection with the first two implementation areas, as measured by our bike-share indicators. However, we also recognize the importance of moving to a city-wide network, accessible to all residents. The decision to expand to these outlying areas should be contingent on the success of phases 1 and 2.

Demand Estimates

Having identified geographic boundaries for proposed implementation phases, we then proceeded to estimate the level of demand within those areas. To do this, we once again leveraged the methodology introduced by Philadelphia, incorporating survey data from European systems.

In recommending potential implementation areas, it is assumed that a contiguous network that minimizes distance between stations is a critical characteristic of successful bike-share systems.

Trip Estimates

Survey data from users of existing systems provided us with baseline diversion rates for various transportation modes. Specifically, users of existing systems were asked, what mode would they have used to make their trip if not for the bike-share system? Note that, in some instances, users indicated they would not have made the trip at all—indicating a new trip rate in addition to the existing mode diversions. This data is presented in Table 4 in the Analytical Method section.

The survey-generated diversion rates were applied to TAZ-level trips in Seattle to produce an estimated range of daily bike-share trips in each proposed phase of implementation. The Phase 3 implementation area did not have a good geographic match with the TAZ boundaries. To compensate for this discrepancy, a ratio of implementation area to TAZ area was applied to the trip estimates to correct for the over-estimation. The results were provided in three scenarios—low, medium, and high—based on the low, medium, and high diversion rates. The analysis showed that the proposed Phase 1 will produce between 2,600 and 6,800 daily bike-share trips; Phase 2 will produce between 1,900 and 4,800; and Phase 3 will produce between 300 and 800. Appendix A provides a table showing the number of bike-share trips diverted from each mode of transportation in each proposed phase of implementation.

Bicycle Demand Estimates

To estimate the number of bicycles needed for the program, we again reviewed information from existing systems. After reviewing various methods for calculating an adequate level of

Proposed Seattle Bike-Share Implementation Phases

SEATTLE BICYCLE SHARE feasibility study

University of Washington
Bike Share Studio

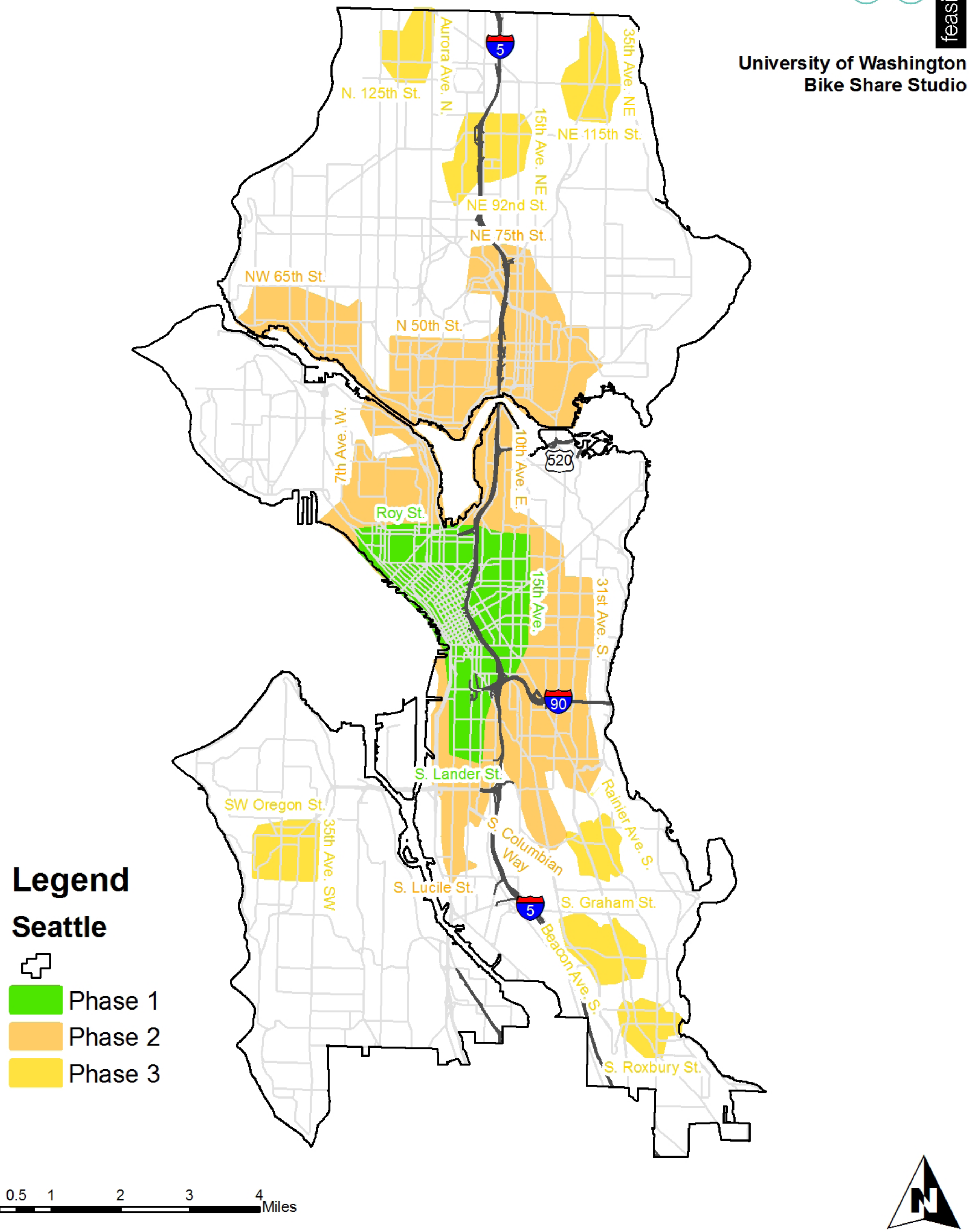


Figure 3: Proposed Seattle Bike-Share Implementation Phases

bicycle deployment, we settled on using an average of trip-generated and station-generated demand estimates. The final demand estimates were provided within a range, low to high.

- **Trip-Generated Demand**: The trip-generated demand was based on data that indicated, on average, that a bike-share bicycle is used 7.67 times per day. To calculate demand in this manner, we used the number of daily bike-share trips originating from our trip estimates, discussed earlier in this section. Although the trip estimates provided low, medium, and high scenarios, we used only the low and medium figures. Using the high scenario would have produced bike-sharing rates in Seattle higher than those in its peer European cities. Given that bike-sharing is relatively new in North America, we thought that this was unlikely to happen, so we used the low and medium scenarios to estimate demand. To estimate the number of trip-generated bicycles needed, we calculated by using what we know:

  Trip-Generation Demand for Bicycles: number of bicycles = number of daily trips ÷ trips per bicycle (7.67)

- **Station-Generated Demand**: The station-generated demand was based on standard supply-side equations used by bike-share vendors and peer cities in Europe. Assuming 15 bicycles per station, a station density, or stations per square mile, criterion was applied to each proposed implementation area to generate the number of bicycles needed. Research and industry best practices indicated that 15 bicycles per station is an appropriate number.[61] Given that our proposed Phases 1, 2 and 3 implementation areas had significantly different land-use patterns and relative bike-share demand, we adjusted the equation to use different station densities for different phases of implementation. We assigned the proposed Phase 1 a station density of 20 stations per square mile. This density is the accepted industry minimum density to support a fully optimized bike-share operation in key destination areas. The proposed Phase 2 and Phase 3 implementation areas were assigned a station density of 10 stations per square mile. This density is more appropriate for residential areas that produce mostly origin bike-share trips and follows an accessibility-based standard. The standard is based on the fact that all residents should be within a 5- to 10-minute walk of a bike-share station. To estimate the number of station-generated bicycles needed, we can calculated as follows:

  Station-Generated Demand for Bicycles: number of bicycles = station density (20 stations per square mile for Phase 1 and 10 stations per square mile for Phase 2 and 3) * implementation area (square miles) * bicycles per station (15)

On the basis of our analysis, this indicated an estimated range of 800 to 1000 bicycles for the proposed Phase 1 implementation. For Phases 2 and 3, estimates ranged from 1,100 to 1,200 and 360 to 380 bicycles, respectively, for a potential maximum of nearly 2,500 bicycles. Table 5 summarizes the results of the bicycle demand estimation. In comparison,

61 JzTI and Bonnette Consulting. Philadelphia Bikeshare Concept Study. Philadelphia: Delaware Valley Regional Planning Commission, 2010.

Barcelona has approximately 6,000 bicycles in its system, Lyon has 4,000, Paris has 20,000, and Washington, D.C., has 120.

Table 5: Bicycle Demand Estimates by Proposed Phases of Implementation

		Phase 1	Phase 2	Phase 3
	Density (station per square mile)	20	10	10
Low Bicycle Demand	Trip-Generated Demand	341	179	37
	Supply-Generated Demand	1,245	2,049	675
	Final (Average)	793	1,114	356
High Bicycle Demand	Trip-Generated Demand	712	422	75
	Supply-Generated Demand	1,245	2,049	675
	Final (Average)	978	1,235	375

Bicycle Station Demand Estimates

By using the proposed implementation area boundaries and recommended standard for number of bicycles per station, we were able to calculate the expected number of stations necessary for the identified implementation areas. Research and industry best practices suggest that each station should contain docking for about 15 bicycles.[62] This figure is used only as a general guideline for estimating the number of stations needed for implementation. When the exact size of each station is planned, it is possible that some stations should contain more or less than 15 bicycles. However, the exact station placement and size was beyond the scope of this study. Therefore, calculations follow the form:

Number of bicycles / bicycles per station (15) = number of stations

Station estimates for each phase had the following ranges: 53 to 65 for Phase 1, 76 to 85 for Phase 2, and 24 to 25 for Phase 3. Table 6 displays the number of bike-share stations for the proposed Phases 1, 2 and 3.

Table 6: Bike-Share Station Estimates by Proposed Phases of Implementation

	Phase 1	Phase 2	Phase 3
# Stations Low (Bikes / Bikes per station (15))	53	76	24
# Stations High (Bikes / Bikes per station (15))	65	85	25

62 JzTI and Bonnette Consulting, Philadelphia Bikeshare Concept Study, (Philadelphia: Delaware Valley Regional Planning Commission, 2010); 72.

Potential Impacts of Climate and Culture

Our methodology for determining trip diversion rates relied on data from cities with existing bike-share programs. To provide some context for this comparison, we researched variables relating to climate and culture. However, little empirical data exist that would show the true impact, if any, of these variables on bike-share ridership.

While we believe using diversion rates from cities with existing bike-share programs is the best method for estimating potential demand in Seattle, the validity of this approach depends on the similarity of these cities to Seattle.

Although we cannot say the degree to which each of the following will influence bike-share ridership, below are our hypotheses regarding their effects:

- The amount of winter rainfall in Seattle is at least twice that of our comparison bike-share systems. The amount of precipitation during other seasons is comparable to other cities. This implies that using diversion rates from other cities will overstate Seattle ridership. However, because the diversion rate data are provided only annually, it is unclear how much, if any, this rainfall difference will affect our estimates.
- Seattle experiences more rainy days than Barcelona during all seasons, and two to four more days per month than Paris and Lyon during the winter season. However, it experiences fewer days of rain than Paris and Lyon in the summer and comparable amounts during the spring and fall. Therefore, using diversion rates from other cities might overstate ridership for winter months and understate it for the summer.
- Seattle's temperatures are approximately ten degrees lower than Barcelona's in every season and within five degrees of Paris and Lyon's in all seasons. Temperature is therefore unlikely to have a great effect on diversion rates.
- Seattle has similar bicycle mode share, but substantially higher automobile mode share and lower transit mode share. Furthermore, Seattleites make more walking trips than citizens in some of, but not all, the comparison cities. Because of the lack of empirical data and the variation among comparison cities, it is not clear how the differences will influence Seattle ridership.
- Seattle has significantly lower population density than our comparison cities; it is at least 10 percent as dense as Paris and 25 percent as dense as Lyon. While public transit systems generally work better in denser environments, the extent of this effect on bike-share is unclear.
- Seattleites own more cars per capita than residents of other cities with bike-share systems—50 percent more than Lyonnais and three times as many as Parisians. Because automobile ownership is generally regarded as a primary determinant of

mode choice, this could decrease the number of bike-share users relative to other cities.[63]

- While topography affects route choice within cities (users tend to use bike-share for downhill trips and other modes for up-hill trips), we uncovered no data to indicate how topography affects overall usage.
- Due to the variations in climate, Seattle may consider operating a three-season system, as is done in Montréal. A seasonal system would likely affect both ridership and costs. While these systems are designed to be easily removed, the operator would still incur additional costs for the removal and storage of the infrastructure. However, there would be little maintenance or operating costs during the winter months. It is unclear what impact a seasonal system would have on total ridership; as mentioned above, Montréal has not yet generated ridership figures and Minneapolis has not yet launched their system.

63 Moshe Ben-Akiva and Steven R. Lerman, Some Estimation Results of a Simultaneous Model of Auto Ownership and Mode Choice to Work, (Transportation , 1974). Accessed at: http://www.springerlink.com/content/v51007r34tqg5748/