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Bike-Share Planning in Cities with Varied Terrain

By Erica J. Wygonik, P.E., Edward McCormack, Ph.D., and Daniel H. Rowe

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Decisions to install public bike-share programs are increasingly based on ridership estimations, but the topography's influence on ridership is rarely quantified. This research evaluated a geographic information system–based approach for estimating ridership that accounted for hills. Double weighting a slope relative to other measures produces a realistic representation of the bicycling experience.

Introduction

Because of their benefits, bike-share programs are increasingly of interest in cities and universities across the country. A bike-share program provides short-term use bicycles to the public through a system of unattended stations for their checkout and return. This affordable form of nonmotorized transportation can reduce automobile dependency, enhance transit use by providing last mile access, and provide an alternative mode to improve transportation mobility.[1]

More than 527 bike-share systems are operating throughout the world.[1,2] A 2012 Institute of Transportation Engineers article listed 26 programs in the United States including programs in Washington, DC; Denver, CO; Boston, MA; and Minneapolis, MN; with more being considered.[1] The decisions about whether and where to establish these early bike-share programs were typically based on professional judgment and personal knowledge of a given city. However, given the growing demand for bike-share systems and the financial constraints on transportation investment, more defensible and quantitative methods for estimating user demand are needed. Bike-share vendors have in-house methods for evaluating infrastructure demands and the associated business viability of systems, but those methods generally are proprietary and not shared with transportation agencies.

To quantify the implementation of a bike-share program in Philadelphia, PA, USA, the Delaware Valley Regional Planning Commission used geographic information system (GIS) software to analyze 10 key indicators.[3] The commission selected factors such as the locations of bike facilities and the population to predict demand for a bike-share program. While this method was analytically strong, the approach did not include topography.

This article presents an approach based on the Philadelphia model, expanded to integrate topography as an indicator of bike-share success, making the approach applicable to a broader range of cities. Typical bike-share users are casual or new bike riders, and hills are a notable challenge to them.[4] Our efforts to enhance the Philadelphia model involved analyzing various ways to quantitatively incorporate topography into a GIS-based bike-share demand analysis. The resulting recommended method accounts for the influence of hills on bike-share feasibility, so it is relevant to cities and regions with varied topography that are interested in evaluating the potential success of a bike-share program.

Previous Demand Estimation Methods

The Delaware Valley Regional Planning Commission used a data-driven analysis for a feasibility study for bike sharing in Philadelphia.[3] To identify the geographic market for bike sharing, Philadelphia used a weighted-sum (different factors have different weights depending on their perceived importance), GIS-based analysis that accounted for the influence of 10 indicators of bike-share demand:

- Population density;
- Noninstitutionalized group population density (such as dormitories);
- Job density;
- Retail job density;
- Locations of tourist attractions;
- Proximity to parks/recreation;
- Proximity to rail stations;
- Proximity to bicycle-friendly streets;
- Proximity to streets with bicycle lanes; and
- Locations of bus stops.

In the Philadelphia analysis, each indicator was selected because it was "intuitively favorable for bike share usage and derived from best practices."[3] The data for each indicator were rasterized (an image described in shapes was converted into a grid of pixels) into a 10-meter-square grid of cells covering the study area. The results for each of the 10 indicators were weighted and then summed in a GIS to produce a composite bike-share value. The planners in Philadelphia then categorized the distribution of values into six distinct score category ranges using geometric interval classification. This classification method ensures each class range has approximately the same number of values and the change between intervals is fairly consistent. The planners in Philadelphia identified the 10-meter grid cells that fell into the top geometric interval classification (indicating the highest likelihood of bike-sharing success) and then selected the region(s) with clusters of these high-scoring cells for phases of bike-share implementation.[4]

As noted, a limitation to the method used in Philadelphia is that it did not address topography. Any person who has bicycled up a hill knows terrain matters, and research has also shown slope angle significantly affects bicycle route choice. For example, analyzing global-positioning-system-observed bike travel in San Francisco, CA, USA, Hood et al., found bicyclists would ride an extra mile to avoid 100 feet of elevation gain.[5] Parkin et al.'s study of bicycle commuters throughout England and Wales found a significant correlation between topography and willingness to ride to work.[6] A similar study used the English and Welsh data to regress a ridership model that incorporated topography and found that a 10-percent increase in hilliness was linked to a 10- to 15-percent reduction in the proportion of people cycling to work.[7] Given that bike-share programs are targeted to a wide range of users, hills may limit bike-share demand. Cities with varied topography need a defensible and quantifiable approach for including the impact of hills in their bike-share ridership analyses. As illustrated in Figure 1, the impact of hills is notable in Seattle, WA, USA, which is transected by a series of ridges served by roads rising more than 300 feet over a half-mile.

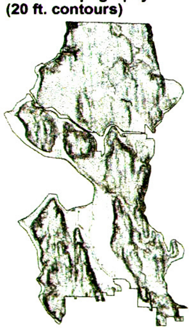

Figure 1. Topography of Seattle, Washington.

Methodology

This research enhanced methodology developed in Philadelphia by developing and evaluating an additional indicator that accounts for hills. Several scenarios were tested, using Seattle as a case study, to find the best method to account for the notable impact of hills on bike riders' choices and to evaluate the addition of slope to the calculation of bike-share demand. The scenarios tested included two approaches to score the slope indicator and three methods to treat the slope indicator in a weighted-sum analysis.

Development of Slope Angle Indicator

The slope indicator was one of 11 components of the weighted-sum raster bike demand indicator analysis (in addition to the 10 indicators originally proposed in the Philadelphia method). The data for the indicators were readily found in city of Seattle and census geographic databases. More details on the data sources are found at the Seattle Bike Share website.[8]

The slope indicator was developed by using widely available 10-meter-grid digital elevation models (DEMs) from the United States Geological Survey (USGS).[9,10] A DEM is "a digital file consisting of terrain elevations for a group of positions at regularly spaced horizontal intervals."[11] By using the spatial analysis tools in a GIS (ArcGIS 9.3.1), the DEM data were converted to a single digital file covering the city of Seattle that quantified the slope angle in 10-meter-square cells. This step allowed integration of the elevation data with the other 10 bike-share indicators.

Scoring the Slope Indicator

Most of the Philadelphia and Seattle bike-share indicators were scored with the quantile method of reclassification, which distributed an equal number of the observed values into each of 10 bins, essentially developing a linear scoring system. This quantile method is known to be a simple classification method for ordinal data used in mapping comparisons.

Because steeper hills may have a larger impact on a rider's physical effort and thus on bicycle ridership than those with only minor slopes, a nonlinear approach that used a manual scoring technique for the slope indicator was also evaluated. With a format similar to that of the quantile method, output from the manual process could be incorporated into the final analysis with the same raster sum methodology.

Routes representing a variety of topographic conditions were subjectively scored by six bicyclists familiar with Seattle to reflect the willingness of a bike-share user to ride the hill. While all of the reviewing cyclists are experienced riders, they represent a cross-section of comfort levels, genders, and riding styles. Daily commuters, mountain bicyclists, road riders, and family riders were included. Scores ranged from 1 (would not ride) to 10 (the topography would have no bearing on the decision to ride). Combining the bicyclist-generated scoring with GIS-based slope measurements generated a map of the relationship between slope angles and perceived level of difficulty. Manual scoring assigned levels of difficulty on an absolute scale rather than relative to other points in the city, as was done with the quantile scoring method.

Weighted-Sum Analysis Scenarios

One of the benefits of a weighted-sum raster analysis in determining a market area for bike sharing is the flexibility it offers. Once all indicators are scored, the final weighting process enables users to adjust each indicator for local conditions and policies. When combined with the other indicators, the weighted-sum analysis produces a composite bike-share score, representing the relative likelihood of bike-share success. These composite scores are used to draw bike-share market-area boundaries. This part of the analysis considered how to weight the topography indicator relative to the other indicators to provide the most likely bike-share demand regions. The weighted sum output can be analyzed using a variety of tools. For these examples, variable shading (choroplethic) maps were found to be the most effective. Such maps can be easily modified in the GIS to match an analyst's preferences.

Three main scenarios were tested to ensure that the slope angle indicator provided a benefit to the weighted-sum process:

- No slope was included, thus applying Philadelphia's method to Seattle.
- The slope indicator was weighted the same as the other indicators.
- The slope indicator was given twice the weight of the other indicators.

The resulting maps for each scenario were evaluated, and select focus areas in the city were analyzed for their suitability as a market area for bike sharing, having terrain appropriate for bicycling in addition to high scores for the 10 nonterrain indicators. Areas with steep hills were further studied for a more detailed evaluation of the three slope-indicator scenarios.

Results

Quantile versus Manual Scoring

Two methods for scoring the slope indicator were analyzed. Figure 2 illustrates the results from the comparison between the processes of using quantile scoring and manually scoring the slope indicator. Minimal differences were observed between the two weighting techniques. However, the manual scoring process required a high level of effort to differentiate between and score the slope samples. Thus, the quantile scoring method was pursued moving forward.

Slope Indicator Weighting

After the slope scoring methods were compared, an appropriate weight for the slope indicator was identified. Single weighting and double weighting were compared to the case with no slope indicator. These weightings were chosen to evaluate the sensitivity of the slope variable and to provide an initial guideline for its use. Further refinement can be completed once data are available to calibrate the model.

In contrast to the results of the scoring techniques comparison, the weighting of the slope indicator was found to have significant impact on the areas of predicted bike-share success. Figure 3 illustrates the results from the three scenarios: no slope indicator, a single-weighted slope indicator, and a double-weighted slope indicator. The figure shows that the darker areas, indicating more likely success for bicycle use based on all indicators, are much larger when slope was not included in the analysis and, as expected, adding terrain into the analysis reduced the attractiveness of bike sharing

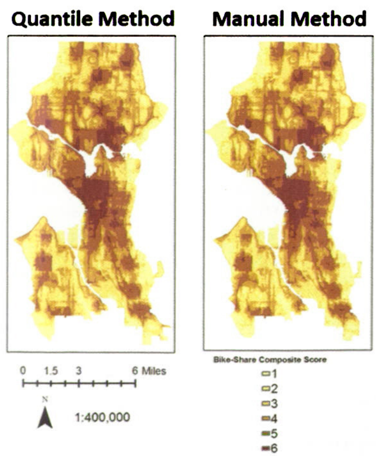

Figure 2. Results of scoring analysis scenarios.

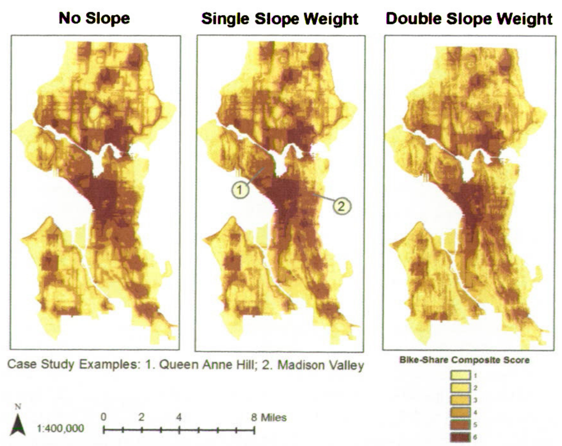

Figure 3. Results of the weighted-sum analysis scenarios.

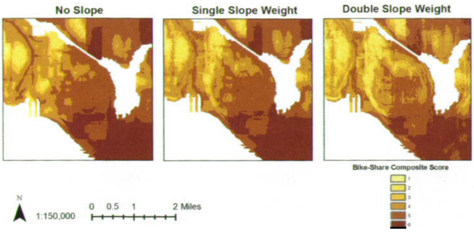

Figure 4. Results of the weighted-sum analysis scenarios for Queen Anne Hill.

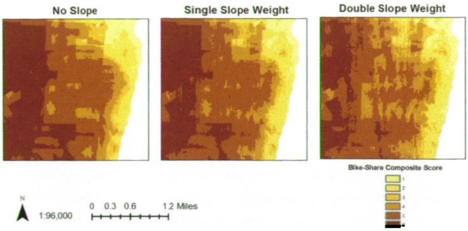

Figure 5. Results of the weighted-sum analysis scenarios at Madison Valley.

in some areas. Double weighting the slope further emphasized this impact, creating smaller areas of predicted bike-share demand.

Seattle has many densely populated neighborhoods just outside the downtown core (the darkest region in the center of the maps in Figure 3). Combined with positive indicator values attributable to interspersed parks, local shops, and strong transit connections, the no-slope analysis highlighted these areas as extensions of the diverse downtown district that would be attractive for a bike-share program.

However, bike-share trips are generally localized, with most systems priced to encourage trips of less than a half-hour. Inclusion of slope in the analysis highlighted the weakness of the connections between the disparate urban centers, resulting in lower scores between urban centers and smaller market areas for bike sharing. These areas represent locations where other modes of transportation, such as public transit, better serve travel needs. Of the two weighting scenarios, the double-weighted slope analysis provided demand estimates more consistent with the bicyclists' knowledge of Seattle.

Case Study: Queen Anne Hill

Examining the above results within the context of specific hilly areas in Seattle illustrated the strengths and weaknesses of each scenario. Queen Anne Hill, identified by the area numbered 1 in Figure 3, rises 456 feet above the Seattle downtown. This hill has some of the steepest slopes in the city, and bike routes up the hill are unattractive. Figure 4 is a close-up of the Queen Anne Hill region for the three quantile weightings (no slope, single weighting, and double weighting).

As shown in the figure, without the influence of slope, the analysis produced dark shading, indicating that Queen Anne should be a region with a higher level of bike-share demand and an attractive destination from the downtown core. Queen Anne is reasonably dense, serves as an urban center, has good transit access, and has a moderate mix of uses—each of which is linked to increased bike-share demand. Adding slope with a weight equal to that of the other indicators reduced the ranking of this region, but moderate levels of bike-share demand were still indicated, inconsistent with the experience of the bicyclists. Only with a double-weighted slope indicator did Queen Anne's overall demand score change significantly, reflecting the actual unattractiveness of this area for bike sharing related to its steep terrain.

Case Study: Madison Valley

The Madison Valley neighborhood provided a different example of the effects of slope inclusion. The district, identified by the area numbered 2 in Figure 3, is a broad, deep valley with a high population density. With only a few main north–south arterials, it has a good level of local transit density and established bicycle facilities. While the entry into the valley from the south is a long, gradual slope, outside the four- to five-block-wide floor of the valley, east–west routes require steep ascents. Figure 5 illustrates the three quantile weighting scenarios for the Madison Valley region. The no-slope results show a broad, even distribution of mostly second-rank cells, coinciding with the area's transit routes, bicycle facilities, and housing densities. However, the single-weight and double-weight maps show the mass of second-rank cells breaking apart. This appropriately reflects the limited bikeability of the neighborhood, despite the otherwise high scores for the bicycle, transit, and population indicators.

Conclusions and Future Work

As bike-share installations are considered more widely, tools are needed to assess potential demand and the feasibility of success of bicycle programs. More quantitative methods have been developed to account for various factors that influence bike use. This analysis extended a comprehensive bike use demand approach developed in Philadelphia by adding and evaluating tools to account for topography.[3] A comparison of quantile (derived from DEMS) and manual (DEMS subjectively weighted by bicyclists) methods for scoring topography indicated that manual scoring produced few relative advantages in accurately delineating bike-share service areas, despite the significant additional effort required by the manual method. In considering the weighting of the slope indicator, a single-weighted slope indicator tempered the other indicators but resulted in demand predictions not fully consistent with knowledge of bicycling in the city. Double weighting the slope indicator produced a more realistic representation of the bicycling experience, appropriately emphasizing the important role of the city's hills in bike-route attractiveness. The areas of high bike-share demand generated by this analysis match closely the proposed Phase 1 implementation area for the 2014 launch of Puget Sound Bike Share, further reinforcing the double-weighting treatment of the slope indicator in bike-share planning.[12]

Therefore, to account for topography, bike-share demand methodologies and any other program evaluating bicycle use in hilly areas should consider including USGS DEM data. These data are a widely available source of information for this indicator. As shown by the analysis described above, these data should be rasterized and scored with a quantile method, and the resulting indicator should be double weighted in the final weighted summation. This method most realistically accounts for the impact of slope on bicycling and is easy to implement within a GIS platform. **itej**

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Works Cited

1. Kahn, R. "Bicycle Sharing in the USA: State of the Art." *ITE Journal*, Vol. 82, No. 9 (September 2012): 32–36.
2. DeMaio, P. "The Bike-Sharing World Map." *The Bike-Sharing Blog* (Updated April 19, 2013), http://bike-sharing.blogspot.com/. [Accessed April 30, 2013.]
3. Krykewycz, G. R., C. M. Puchalsky, J. Rocks, B. Bonnette, and F. Jaskiewicz. "Defining a Primary Market Area and Estimating Demand for Major Bicycle-Sharing Program in Philadelphia, Pennsylvania." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2143 (2010): 117–124.
4. Shaheen, S. A., S. Guzman, and H. Zhang. "Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2143 (2010): 159–167.
5. Hood, J., E. Sall, and B. Charlton. "A GPS-Based Bicycle Route Choice Model for San Francisco, California." *Transportation Letters: The International Journal of Transportation Research*, Vol. 3, No. 1 (January 2011): 63–75.
6. Parkin, J., M. Wardman, and M. Page. "Estimation of the Determinants of Bicycle Mode Share for the Journey to Work Using Census Data." *Transportation*, Vol. 35, No. 1 (2008): 93–109.
7. Parkin, J., T. J. Riley, and T. J. Jones. "Barriers to Cycling: An Exploration of Quantitative Analyses." *Civil Engineering* (2007) http://digitalcommons.bolton.ac.uk/ce_chapters/1. [Accessed July 10, 2010.]
8. Gregerson, J., M. Hepp-Buchanan, D. Rowe, J. Vander Sluis, E. Wygonik, and M. Xenakis. "Seattle Bicycle Share." http://seattlebikeshare.org/.
9. Gesch, D. B. *The National Elevation Dataset*, in Maune, D., ed., *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd Edition. Bethesda, MD: American Society for Photogrammetry and Remote Sensing, 2007, pp. 99–118.
10. Gesch, D., M. Oimoen, S. Greenlee, C. Nelson, M. Steuck, and D. Tyler. "The National Elevation Dataset." *Photogrammetric Engineering and Remote Sensing*, Vol. 68, No. 1. (2002): 5–11.
11. Rocky Mountain Mapping Center. "What is DEM." U.S. Geological Survey, 2001. http://rmmcweb.cr.usgs.gov/elevation/dpi_dem.html. [Accessed July 10, 2010.]
12. The Bike Share Partnership. "King County Bike Share Business Plan." Alta Planning + Design, 2012. http://pugetsoundbikeshare.org/wp-content/uploads/2012/07/KCBS_Business_Plan_FINAL.pdf. [Accessed August 27, 2013.]

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