Economic Impact & Operational Efficiency for Bikeshare Systems

Local, Domestic & International Lessons

Virginia Tech

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1 INTRODUCTION

This report presents findings and recommendations regarding two bikesharing-related issues: potential economic impacts and the balancing problem. We conducted an intercept survey of bikesharing users and walk-up surveys of businesses to determine the extent and nature of bikeshare's economic impact in five Washington, DC neighborhoods. To study the balancing issue, we surveyed bikesharing systems about their problems with and strategies for re-balancing and then analyzed a data sample from the Washington, DC system, Capital Bikeshare ("CaBi"). By "the balancing problem" we mean instances in which bikes in a bikesharing system are unevenly distributed such that stations are completely full or empty. We provide recommendations based on our findings that may help CaBi and other bikesharing systems become more impactful and efficient.

2 ECONOMIC IMPACT REPORT

Background on Bikesharing and Capital Bikeshare

Bikesharing has evolved in recent decades and gained widespread adoption in Europe as well as North America and Asia. Earlier generations of bikesharing ranged from free, unlocked bicycles distributed throughout a city (e.g. Amsterdam) to formal stations with sturdy bicycles specially designed for utilitarian use. In today's third generation of bikesharing, paying members can check-out a bicycle from a station and return the bicycle to any station in the system (DeMaio, 2009; Shaheen, Guman, & Zhang, 2010). Riders pay a variety of member and usage fees depending on the type of membership chosen (daily, weekly, monthly, or annual). Bikesharing is a transportation mode that encourages cycling and can also serve as a "first mile/last mile" connection for public transport users (Shaheen, Guzman, & Zhang, 2012). Bike share user behavior is classified by patterns of pickups and returns, and studies of multiple systems classify user behavior into commuters, tourists, and leisure groups (Vogel & Mattfeld, 2011).

Bikesharing has experienced a dramatic expansion in recent years, especially in the U.S. By the end of 2012, there were approximately eight times as many systems in the U.S. as there were in 2007 (Kurtzleben, 2013). The expansion can be explained by many factors, including the desire of both users and city leaders to increase mobility options, reduce traffic congestion, improve public health, and increase environmental awareness (Shaheen, Guman, & Zhang, 2010). Companies such as Alta and B-cycle are now operating in multiple U.S. cities with similar bicycles, stations, and membership options.

This research paper focuses on the CaBi system in Washington, DC. CaBi was launched in September 2010 in the District of Columbia and Arlington County, VA. It has since expanded to Alexandria, VA and Montgomery County, MD, reaching 300 total stations system-wide by the end of November 2013. (See Table **2.1** for the number of stations per jurisdiction.) Users can purchase annual, monthly, 30-day, 1-week, or daily memberships. Furthermore, there is an additional usage fee once riders have checked-out a bicycle for more than 30 minutes.

Table 2.1.

Number of CaBi stations by jurisdiction.

Jurisdiction	Number of Stations
Alexandria, VA	8
Arlington County, VA	64
Montgomery County, MD	41
Washington, DC	187
Total	300

Source: CaBi

Economic Impacts of Bikesharing and Bicycling

Bikesharing has significant transportation and environmental impacts (DeMaio, 2009; Shaheen, Guzman, & Zhang, 2012) and has received increasing attention from an economic perspective as well (Schoner, Harrison, & Wang, 2012). As bikesharing investments are considered, there is increasing interest from policymakers and citizens about the economic impacts of bikesharing on the community. This research report investigates the economic impact of bikesharing in Washington, DC by asking two questions:

- What are the spending patterns of bikeshare users around their destination stations?
- How do businesses perceive the impact of bikesharing on their bottom line and their neighborhood?

To study the economic impact of bikesharing, we conducted two surveys. The first survey was of CaBi users. We intercepted CaBi users who returned bicycles to five stations in Washington, DC and employed a survey instrument that asked participants why they traveled to the station, if they intended to spend money, and what they might have done without a CaBi station in the neighborhood. Membership and demographic questions were also asked. By surveying users, this report examines CaBi's economic impacts from the customer perspective to determine if CaBi induces new trips to neighborhoods and if it generates new or additional customer spending.

We administered the second survey to businesses around the same five stations that the user surveys were conducted. We surveyed businesses in the retail, arts, entertainment, recreation, accommodation and food service sectors. The survey included questions about a business' employees, customer base, changes in sales that might result from CaBi, and how the business would react to CaBi expansion scenarios. By surveying nearby businesses, this report also examines whether businesses believe that CaBi has impacted their bottom line and whether businesses would support its expansion.

By utilizing this approach, the research makes a unique contribution to the existing body of research on bikesharing systems. First, whereas previous studies show the number of induced customer trips (Capital Bikeshare, 2013; Schoner, Harrison, & Wang, 2012), this study seeks to measure how much money is being spent by individuals making those induced trips. We also investigate how close to the station users will spend money. These findings will help local officials and business leaders determine if, when, and where a bikesharing system is appropriate for their community.

Second, this study evaluates how businesses near bikesharing stations perceive the system. By investigating both the perceptions of local businesses as well as their preferences regarding public space trade-offs, our report may help local officials to better collaborate with the business community when proposing new bikesharing systems or expanding existing systems.

This report is composed of the following sections. First, we provide an overview of literature regarding the economic impact of bikesharing and bicycling in general. Next, we describe the user survey in detail, including how we surveyed users and how we selected stations. We then describe the development and deployment of the business survey. Next, we share the results of and analyze both surveys. We conclude with recommendations for bikesharing operators and local leaders.

LITERATURE REVIEW

Research on the economic impact of bikeshare is limited, though some studies have addressed the economic impacts of cycling in general. Topics that have received attention in recent literature include spending levels as determined by mode choice (bicycle versus automobile,

etc.), whether the presence of bikeshare induces new trips that otherwise would not have occurred, and business perceptions of bikeshare and bicycling.

The majority of research on spending habits by mode choice has suggested those who cycle typically spend money at higher levels than those who drive (Clifton, Morrissey, & Ritter, 2012; Flusche, 2012). A report commissioned by Smart Growth America (2013) found that bikeshare creates a "green dividend" by making it easier for people to reach destinations without relying on an automobile. Clifton et al. (2012) explored whether mode choice resulted in differences in spending at bars, restaurants, and convenience stores in the Portland, OR area. While bicycle users spent less per trip than automobile users, they accounted for more frequent store visits per person and therefore made up a larger share of overall per person spending (Clifton, Morrissey, & Ritter, 2012). Flusche (2012) highlighted very similar findings from another study of the Bloor Street commercial corridor in Toronto (Canada) in which people who either biked or walked to the area stated that they spent more money per month than those who drove. Finally, in a study of Minneapolis' NiceRide system, Schoner et al. (2012) examined correlations between bikeshare activity and proximate businesses and places of employment. They found that bikeshare activity increases with the number of food-related businesses within a ⅛ mile walk of the bikeshare station (Schoner, Harrison, & Wang, 2012). No study to date has generated a quantitative estimate of the economic benefit of this increased bikeshare traffic.

Looking to the topic of induced trips and consumer patterns, streets with infrastructure that make active travel safer and more enjoyable attract potential pedestrian and bicyclist patrons to stores along these streets (Meisel, 2010; Smart Growth America). Specifically, in a previous study of CaBi users, researchers found that 83 percent of respondents indicated that they were "more likely to patronize a business…located near a CaBi station" (Flusche, 2012). The Schoner et al. (2012) study focusing on NiceRide users indicated that although the system mostly facilitated mode shifts to bikeshare from other travel modes, a small but notable number of induced trips did occur. Although both of these surveys have given insight into bikeshare's ability to induce trips and visits to local businesses, neither investigates spending levels associated with induced trips.

The third topic explored by previous research was that of businesses and their perceptions of the impacts from bicycling and active travel. Most studies found that businesses typically viewed bikesharing systems positively and perceived that bikeshare, along with other bike infrastructure investments, presented positive externalities for their businesses. In a Smart Growth America (2013) study, businesses along Victoria Street in San Francisco's Mission District reported a 60 percent increase in sales due to increased pedestrian and bicycle traffic after the installation of a new bike lane. Meisel (2010) estimated that, because the addition of one to two bike corrals allows 10-20 cyclists to use the same space used by one to two automobiles, replacing car parking spaces with bike corrals could increase parking capacity by 400-800 percent. A bike corral with relatively low occupancy (e.g. one to two bicycles) is still likely to accommodate at least as many potential customers as a single car parking space (Meisel, 2010). Ultimately this benefits businesses by allowing more customers to park outside of their establishments (Meisel, 2010). Furthermore, in a study of Portland, OR businesses abutting corrals, respondents considered the on-street bike parking facilities to be a "pro-business amenity" (Flusche, 2012). Business respondents felt that bike corrals generally "enhance the street and neighborhood identity, help promote sustainability, increase transportation options for employees and patrons, increase foot and bike traffic, increase the visibility of the businesses from the street, and improve the sidewalk environment for patrons" (Flusche, 2012). Many businesses in the study area were investing in creating a more bike friendly image with the goal of attracting customers (Flusche, 2012).

A number of recent studies have suggested that there is a spectrum of support for bikesharing across the business community, with support of bikesharing weighed in relation to other needs and facilities (LoSapio, 2013; Schoner, Harrison, & Wang, 2012). Schoner et al (2012) found that bikeshare activity held positive associations solely with food and drink establishments and that these types of businesses generally had positive opinions of bikeshare. Nevertheless, very few of these businesses would be willing to remove car parking or sidewalk space for additional bikeshare stations (Schoner, Harrison, & Wang, 2012). LoSapio conducted a study of businesses in proximity to Dupont Circle CaBi stations in Washington, DC with the goal of investigating the impacts businesses perceived the system had on their establishments. While business owners were not particularly aware if their customers arrived by CaBi, a quarter of the business owners

surveyed would be willing to tap into this market via incentives such as discounts for CaBi members (LoSapio, 2013). Key to LoSapio's study was its location within the Dupont Circle neighborhood, a dense, mixed-use area accessible by multiple other modes of transportation such as Metrorail, bus, and carshare. The Dupont Circle CaBi station used in the present study is the busiest in the system; business owners may not be as concerned with how customers arrive because the area experiences such high customer traffic. It also may be difficult for them to determine each customer's mode choice without asking directly.

This study makes a unique contribution by exploring differences in perceptions of bikeshare held by businesses based on distance from other major transit modes, such as Metrorail. In particular, we investigated whether those businesses further away from rail service perceive greater impacts from the presence of a bikeshare station. Thus, our research aimed to add to the literature in three ways: 1) by gathering data on business perceptions and user activities at bikeshare stations that are significantly removed from a heavy rail station; 2) by examining both users and businesses within the same neighborhoods and around the same bikeshare stations, a task which no other research has accomplished; and 3) by quantifying the estimated dollar amount that induced riders add to the local economy via use of bikeshare.

METHODOLOGY

CaBi Station Selection

We used three criteria to select CaBi stations for the user and business surveys:

1. Walking distance of the CaBi station from the nearest Metrorail station
2. Weekend ridership
3. Number of businesses within close proximity of the CaBi station

Most pedestrians are willing to walk about 0.5 miles to or from a rail station, in this case Metrorail (Weinstein, Schlossberg, & Irvin, 2008). We were interested in investigating whether neighborhoods located farther than this commonly accepted walking distance would have a higher economic gain from CaBi than those located near a Metrorail station. We focused on weekends because people have more free time on the weekends and may be more likely to spend money and take an induced trip. By surveying on the weekends, we also reduced the portion of

riders commuting to or from work – a trip type that was seldom identified as an induced trip in CaBi's Annual User Survey (Capital Bikeshare, 2013).

Based on a best route analysis that assumed a walking pace of three miles per hour, we eliminated all stations that were less than a 10 minute walk from the nearest Metrorail station. We then ranked stations based upon the total number of bicycle drop-offs that occurred at the station during weekend hours (Friday afternoon and evening, and anytime Saturday or Sunday) during the 2nd Quarter of 2013. Finally, we ranked those stations in the top 75th percentile of ridership by the number of businesses within a 0.1 mile radius of the station. We used the ReferenceUSA business database to find businesses with North American Industrial Classification (NAICs) codes of:

- 44, 45 - Retail Trade
- 71 - Arts, Entertainment, and Recreation
- 72 - Accommodation and Food Services

Only stations located in the District of Columbia met the above criteria. We chose the top four ranked stations that represented four different neighborhoods. We added a fifth station, located near the Dupont Circle Metrorail station, to serve as a control. The final stations were:

- Georgetown (C & O Canal & Wisconsin Ave NW)
- Logan Circle (14th St NW & Rhode Island Ave NW)
- Adams Morgan (Adams Mill Rd NW & Columbia Rd NW)
- H Street (13th St NE & H St NE)
- Dupont Circle (Massachusetts Ave & Dupont Circle) - included for comparison

The Dupont Circle station was chosen as the control station because it is the busiest station in the system, close to Metrorail, and appeared in the exploratory LoSapio study of economic impact of CaBi. By including this station, we could more easily compare our findings with those from LoSapio's previous research and also collect data for control purposes.

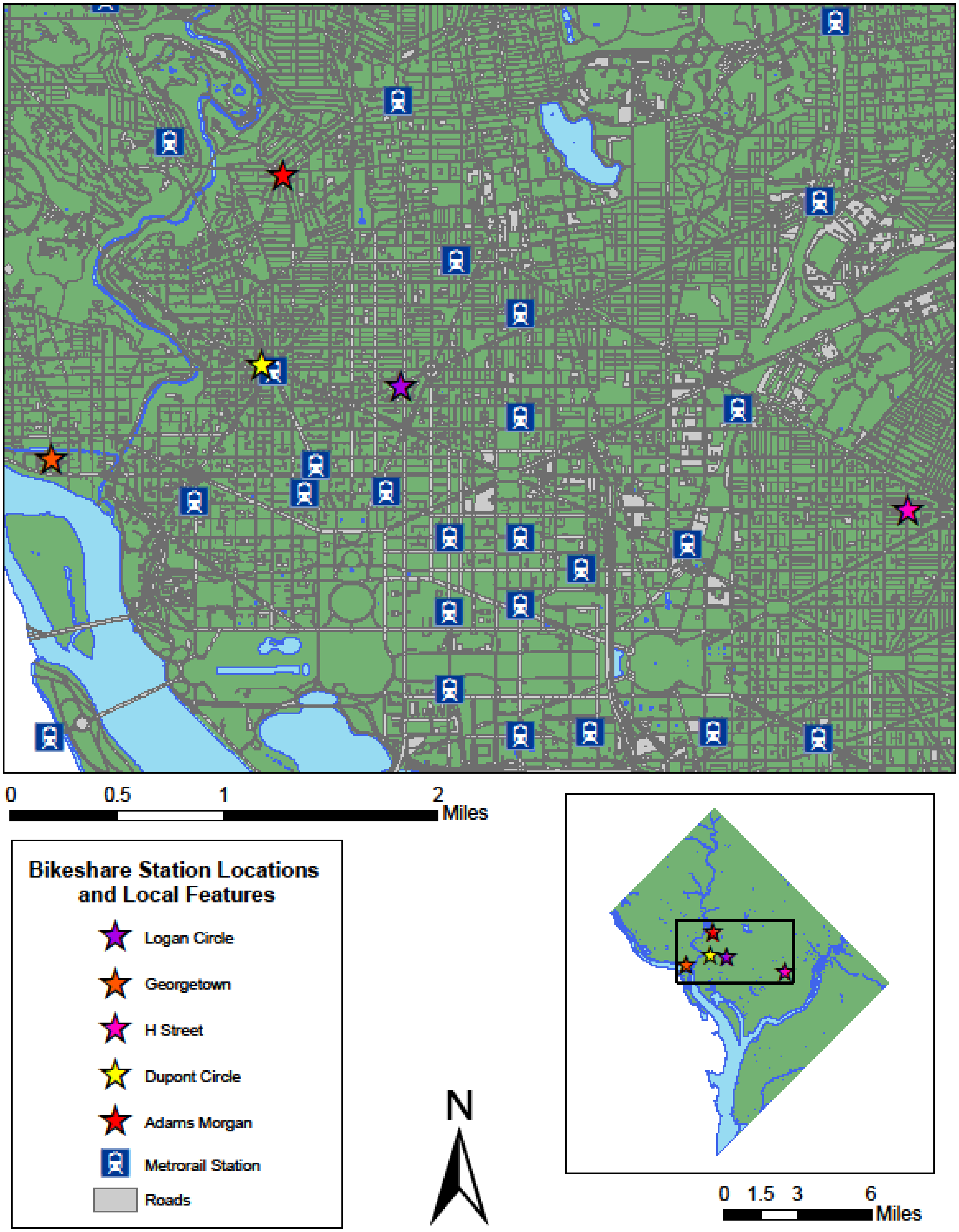

Figure 2.1: Map of selected station locations and Metrorail locations.

User Intercept Survey

Over four weekends in October 2013, we asked CaBi users to participate in a 23-question survey. We approached CaBi users as they returned their bikes to our selected stations. Survey questions were designed to determine the nature of the trip and the destination. Specifically, we sought to determine where the user was traveling; whether the trip would result in a purchase; how close to the station the purchase would most likely occur; the anticipated spending level; whether using CaBi would compel them to spend more than they otherwise would have; and if CaBi played a role in the user's decision to visit the particular neighborhood. In addition, we asked demographic questions relating to sex, income, educational attainment, self-reported cyclist type, and why they used CaBi. A complete list of the intercept survey questions is available in Appendix A.

We collected surveys in two- to four-hour shifts. Typically there were two students at each station, but due to scheduling difficulties some shifts were completed by only one student. We intended to spend an equal amount of time surveying at each selected station location. However, some locations yielded very few completed surveys per hour. In order to increase our sample size, we allocated more survey collection hours to locations with higher ridership and higher survey respondent rates (see Table 2.2). Due to the targeted station selection criteria described above, the study sample is most representative of economic impacts surrounding stations with high commercial activity and further distance from Metrorail.

Table 2.2.

Surveys collected and time spent surveying by location.

Station Location	Hours Spent Surveying	Surveys Collected	Surveys Collected in Percent	Rate of Return
Georgetown	24	131	39%	5.5/hr
Logan Circle	16	83	25%	5.2/hr
Adams Morgan	8	30	9%	3.8/hr
H Street	8	14	4%	1.8/hr
Dupont Circle	10	75	23%	7.5/hr
All Stations	66	333	100%	5/hr

Business Perceptions Survey

Over five weeks between late-October and mid-November 2013, we conducted in-person surveys of businesses surrounding the same bikeshare stations at which the user intercept surveys were conducted. These surveys collected information about a business' knowledge of CaBi; the perceived impacts of CaBi on their business; whether the presence of the system has any effect on businesses decisions; interest in offering discounts to CaBi users; and how willing the business would be to accommodate new CaBi stations in car parking and pedestrian spaces immediately outside of their business. The business perceptions survey is reproduced in Appendix B.

FINDINGS

User Intercept Survey

Demographics

A total of 333 riders completed surveys after dropping off a CaBi bike at one of the five selected stations. Survey respondents fit a similar demographic profile to CaBi's Annual Member Survey respondents (Capital Bikeshare 2013a). The economic impact user survey respondents were slightly younger (67% under age 35, versus 63%), more likely to be male (65% versus 57%) and less likely to have an advanced educational degree (53% versus 56%). The household income of the respondents in both surveys was virtually the same. All differences were slight, thus indicating that generally this study is a good representation of CaBi's overall annual member ridership. See Figure 2.2 through Figure 2.5 for demographic comparisons among respondents of the CaBi Annual User Survey 2013 and the Economic Impact User Intercept Survey.

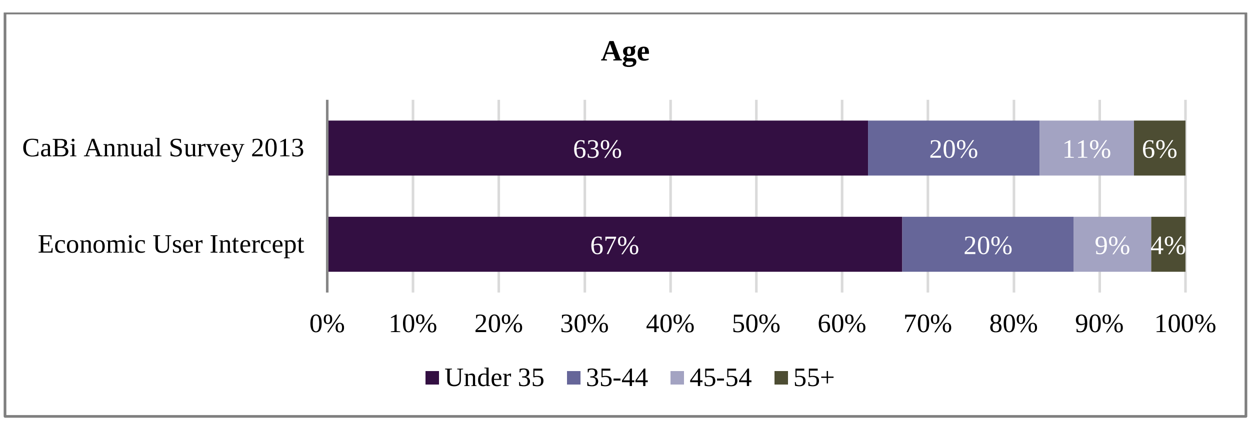

Figure 2.2. Comparison of survey respondents' age - CaBi Annual User Survey vs. Economic User Intercept Survey

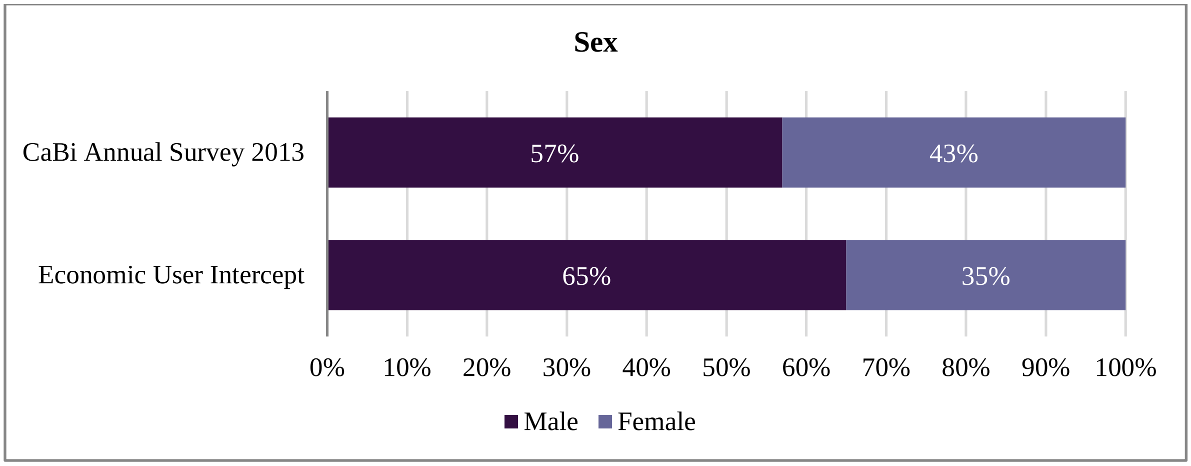

Figure 2.3. Comparison of survey respondents' sex - CaBi Annual User Survey vs. Economic User Intercept Survey

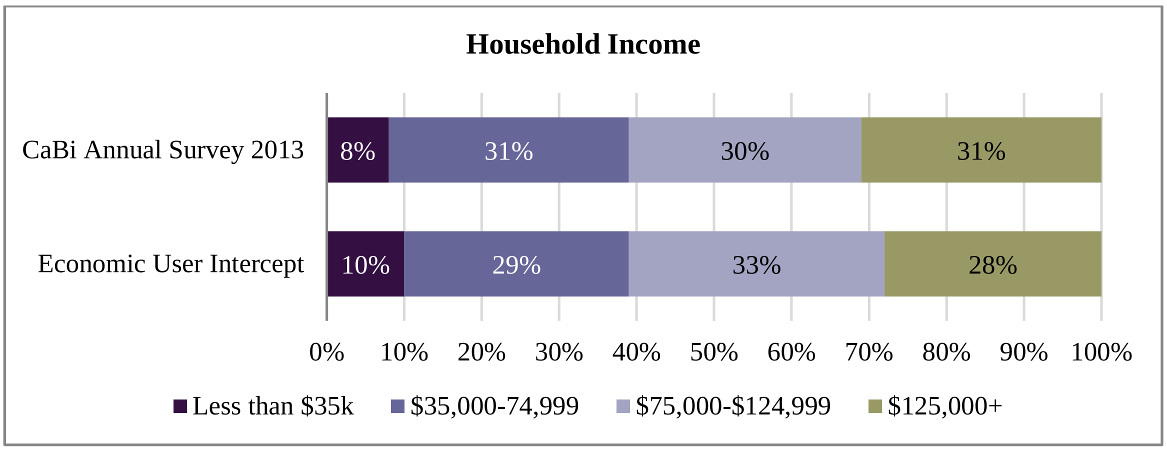

Figure 2.4. Comparison of survey respondents' household income - CaBi Annual User Survey vs. Economic User Intercept Survey

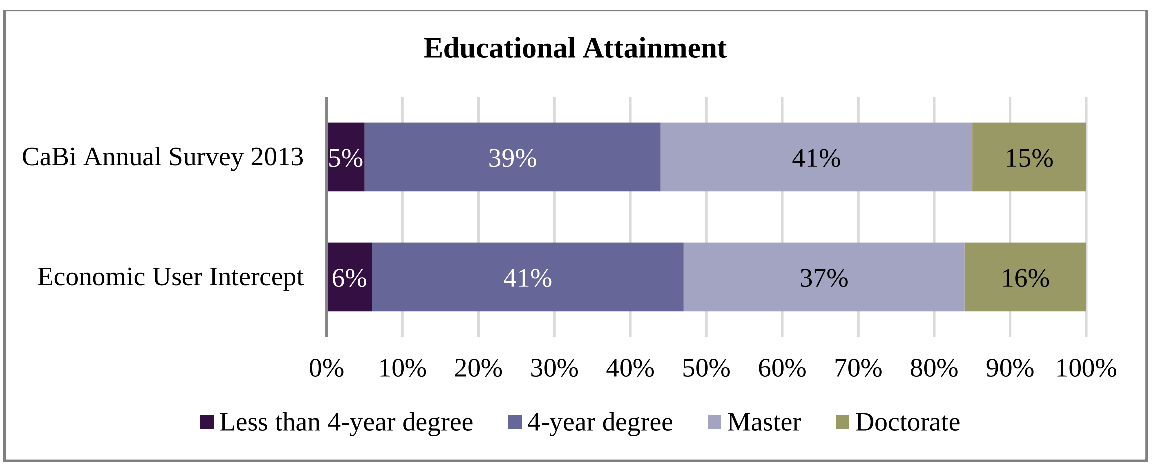

Figure 2.5. Comparison of survey respondents' educational attainment - CaBi Annual User Survey vs. Economic User Intercept Survey

Most riders were under the age of 35 (67%). The majority of riders surveyed were male (65%). More than half of respondents (53%) reported having attained a master's degree or higher and nearly all respondents (94%) had a bachelor's degree. Respondents' household income was higher than the city as a whole with only 10% of respondents reporting a household income less than $35,000 and over a quarter with a household income above $125,000. And approximately 63% of survey respondents were Annual members, whereas another 22% were 24-hour members.

Motivations for Using CaBi

CaBi users most often cited speed as a motivation for using CaBi. Most users (73%) said they took CaBi because it was a faster way to get to their destination. Other frequently cited reasons for taking CaBi were to have fun (42%), to get exercise (41%), to save money (25%), or because the destination was too far to walk (25%).

Overall Spending Patterns

CaBi users were most often traveling to a destination associated with spending money. Survey respondents were asked to indicate the types of destinations to which they were headed after dropping off their CaBi bike. We collapsed these destination types into two categories: spending destinations (retail store, neighborhood service, arts/entertainment, and eating/drinking establishment) and residential destinations (own residence, friend/family residence, or hotel). Most riders reported traveling to a spending destination (66%) while about one third (34%) cited a residential destination.

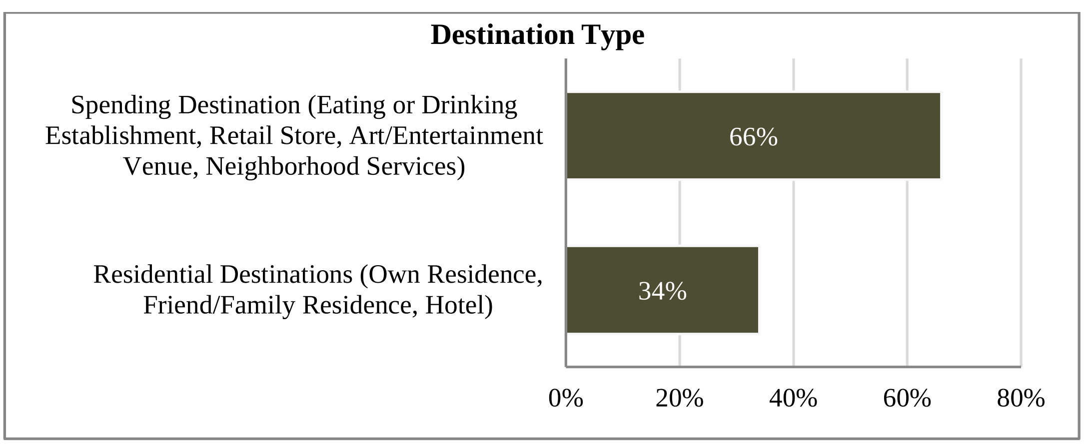

Figure 2.6. Destination type, all respondents.

CaBi trips are associated with spending near CaBi stations. Of those who lived outside of the neighborhood, 86% reported that they planned to spend money in the neighborhood. Of those who planned to spend money (both those living outside and within the neighborhood), 79% said they would spend money within four blocks of the CaBi station where the drop-off was made (see Figure 2.7). The majority of riders (63%) who planned to spend money estimated their purchase would fall between \$10 and \$49, while nearly one third (30%) planned to spend \$50 or more (see Figure 2.8).

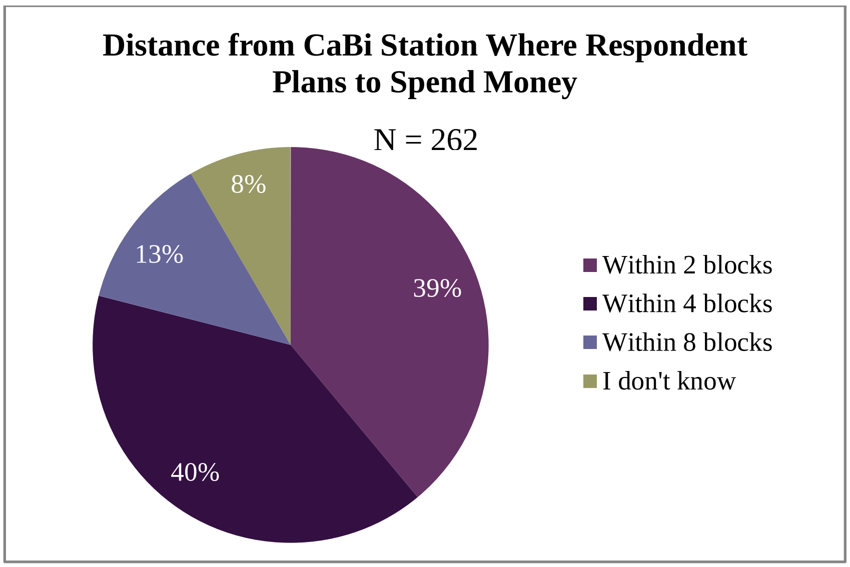

Figure 2.7. The distance from the CaBi station where the respondent plans to spend money, all respondents.

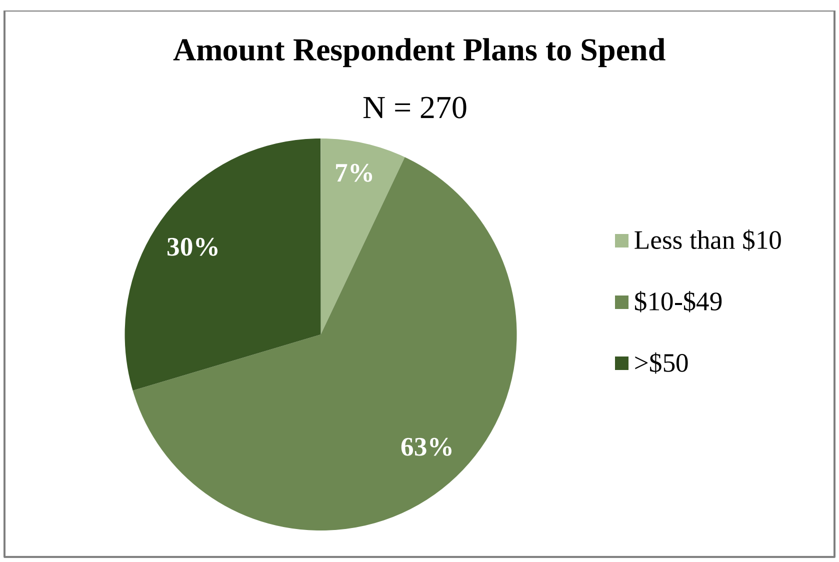

Figure 2.8. Amount respondent plans to spend in the neighborhood during this trip, all respondents.

CaBi users who planned to spend money will return to the neighborhood frequently. Of those survey respondents who planned to spend money, 64% reported that they would return to the neighborhood on a daily or weekly basis.

Amount and location of spending depended on neighborhood, and income.

- Respondents dropping off their bike in Georgetown planned to spend a higher amount of money than respondents at other stations.
- A majority of riders in all income groups planned to spend money on their current trip. At least 86% of those making $35,000 or more planned to spend money, while 59% of riders with a household income of $34,999 or less planned to spend money.
- See Appendix C for charts related to the key variables.

Impact of environmental factors on survey results

Users who completed the survey during the October 2013 federal government shutdown were more likely to spend money (90% versus 79%) and more likely to take an induced trip (82% versus 73%). It is unclear whether the government shutdown was solely responsible for this variation because the shutdown also corresponded with higher temperatures (and therefore more favorable riding conditions).

Table 2.3 shows the mean temperature, precipitation, and status of government for each user intercept survey collection day.

Table 2.3.

Environmental conditions during survey collection days: weather and the federal government shutdown.

Survey Collection Date	Mean Temperature (°F)	Precipitation	Government
Friday, October 4th	79	0 in	Shutdown
Saturday, October 5th	80	0 in	Shutdown
Sunday, October 6th	68	1.13 in	Shutdown
Friday, October 11th	62	2.76 in	Shutdown
Saturday, October 12th	66	0.29 in	Shutdown
Sunday, October 13th	63	0.03 in	Shutdown
Federal Government Reopens			
Friday, October 18th	61	0 in	Open
Saturday, October 19th	60	0 in	Open
Sunday, October 20th	58	0 in	Open
Friday, October 27th	53	0 in	Open
Saturday, October 28th	55	0 in	Open
Sunday, October 29th	55	0 in	Open

Induced Trips

CaBi generates trips that would not have otherwise been taken. In addition to demonstrating that CaBi users spend money near CaBi stations, our survey found 16% of survey respondents made an induced trip–that would not have been taken without the presence of CaBi in the particular location. Of the riders who took an induced trip, 19% would have stayed home without CaBi demonstrating that CaBi is responsible for some new spending. The other 81% of induced trip takers would have traveled to another neighborhood. This is an important finding for neighborhoods and business improvement districts looking to increase their share of the region's existing spending.

Induced trips generate new spending near CaBi stations. Those taking an induced trip also planned to spend money (81%) at the same amount and within the same distance of the CaBi station as the sample as a whole.

Induced trip takers differ from other respondents. Those who made an induced trip were more likely to be annual members (68% vs. 63%) and have a household income higher than $75,000 (78% vs. 61%). Moreover, induced trip takers were more likely to visit a spending destination. Induced trip takers were more likely to visit a retail store, eating and drinking establishment, arts/entertainment venue, or neighborhood service than those who said they would have visited the neighborhood without the presence of CaBi (85% vs 66%).

Some of those who would have travelled to the neighborhood regardless of CaBi will spend more because of CaBi. Even among those who did not take an induced trip, 19% reported that they would spend more money in the neighborhood than they would have spent if they had not taken CaBi. This finding may reflect a willingness to spend the money saved by choosing CaBi.

The percentage of induced trip takers varied greatly by location but distance from Metrorail was not the driving factor. While we hypothesized that distance from Metrorail would increase the likelihood that the station would attract induced trips, the Dupont Circle station adjacent to Metrorail saw the highest percentage (22%) of users claiming an induced trip.

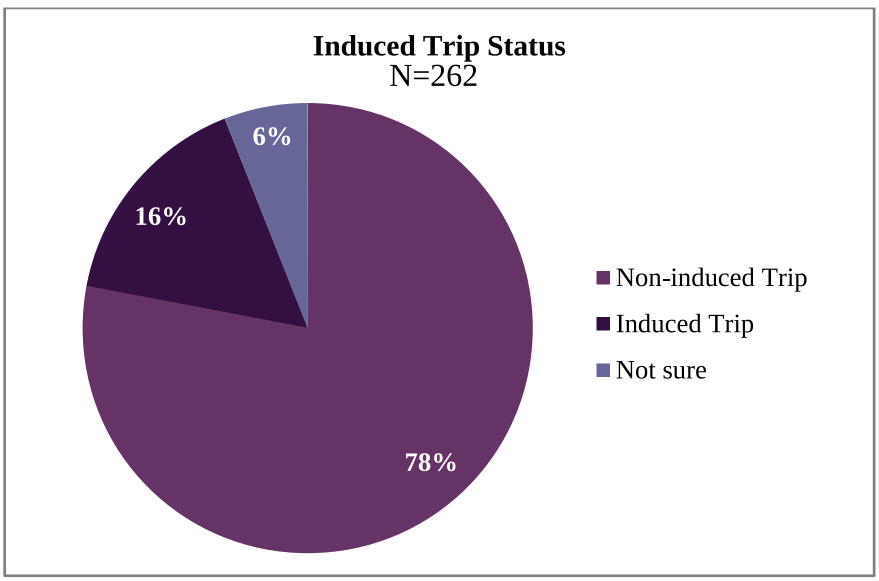

Figure 2.9. Induced vs. non-induced trip: Would respondent have travelled to neighborhood if CaBi station were not present? Those who indicated they would not have travelled to the neighborhood are considered “induced” riders.

Table 2.4.

Induced trips as a percentage of all trips to each station location.

Station Loc	Induced Trips
Dupont Circle (n=75)	22%
Georgetown (n=131)	20%
Logan Circle (n=83)	10%
Adams Morgan (n=30)	10%
H Street (n=14)	0%
All stations (n=326)	16%

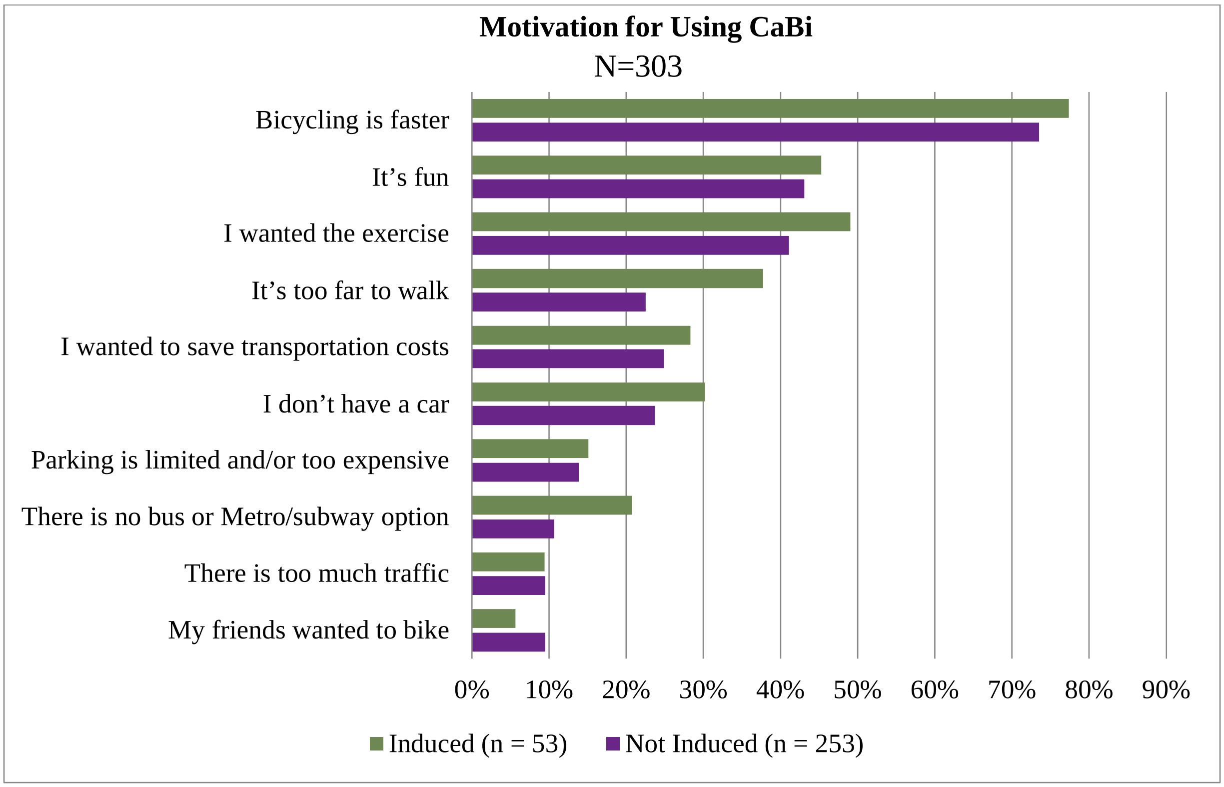

Figure 2.10. Motivation for using CaBi by induced trip status.

Induced trip takers were likely to cite distance and transportation costs as their reason for taking CaBi. Compared with those who would have visited the neighborhood regardless of CaBi’s presence, induced trip takers were 48% more likely to mention a lack of Metrorail or other public transportation as their reason for using bikeshare for their most recent trip. Walking distance, a desire to save on transportation costs, and lack of access to a vehicle also motivated induced trip takers to use CaBi.

Estimated Weekend Revenue

Using the survey responses of riders who took an induced trip and the amount they planned to spend, we estimated the potential revenue CaBi brings to the selected neighborhoods on the weekends. To estimate the revenue that CaBi induced riders spent near each surveyed stations, we applied the spending of induced riders to the ridership volume for each surveyed station. This calculated spending amount would not have been spent or would have been spent in other neighborhoods if the bikeshare station were not present. As with the survey site selection process, we used ridership data from the second quarter of 2013.

Table 2.5.

Estimated weekend revenue for 2nd quarter 2013 by station location.

Survey Station	**Total Estimated Induced Trips**	**Estimated Induced Trips per Spending Category**						**Estimated Spending**	
		Less than $10	$10-$24	$25-49	$50-$74	$75-$99	$100 or more	Lower Bound	Higher Bound
Adams Morgan	334	0	111	111	0	0	110	$14,922	$22,129
Dupont Circle	2,049	256	256	512	256	0	0	$28,171	$53,769
Georgetown	639	25	172	123	25	49	148	$24,469	$35,899
H St NE	0	0	0	0	0	0	0	$0	$0
Logan Circle	383	0	96	192	48	0	0	$8,140	$15,559
Total	*3,405*	*281*	*635*	*938*	*329*	*49*	*258*	*$75,705*	*$127,359*

First, we estimated the number of total induced trips for each surveyed station by multiplying the respective weekend ridership by each station's percent of induced trips on weekends as measured by our survey. We then estimated a total number of induced trips by reported spending category by multiplying the total number of induced trips for each station by the share of each station's induced trips that correspond to each spending category. We estimated a lower bound of total induced revenue per station by multiplying the number of induced trips in each spending category by the lower bound of each spending interval. The higher bound estimate was found by using the highest number in each spending category, although $125 was used as the upper bound of the highest spending level so as not to assume a higher spending level than what respondents

might have reasonably inferred from the $100 or more category. The results are shown in Table 2.5.

Assuming our survey results are representative of typical weekend riders to the selected stations, we estimated that induced trip takers alone spent between $75,000 and $127,000 in the second quarter 2013 at the surveyed stations. Because other bikeshare stations have far fewer businesses located nearby, it may not be appropriate to use the survey station revenue estimates for the entire system. Additionally, although the second quarter is often used as a baseline or reference in the business community, it is also not appropriate to scale our estimates for a yearly revenue total, because ridership levels may change substantially throughout the year due to weather and tourist activity. However, it is important to re-emphasize that many bikeshare riders report spending money during their trips, and many of these riders report that – absent a bikeshare station near their destination – they would have spent that money in another neighborhood or not at all.

Business Perceptions Survey

Businesses Surveyed

Table 2.6 describes the types of businesses and the neighborhood station locations from which responses were gathered. Out of the 140 business responses, 81% were located outside of the Dupont Circle community with Georgetown reporting the highest share (36%) of business respondents. Examining the types of businesses included, 49% were identified as Food/Drink establishments and 42% were identified as Non-Food/Drink establishments with retail operations reporting the highest share of that category (31%). The analysis below aggregates findings for all five CaBi stations. Small sample size precluded analysis of individual stations.

Table 2.6

Business perceptions survey sample.

	Number of Observations	Percentages
Total Sample	*140*	*100%*
Neighborhood Station:		
Adam's Morgan	14	10%
Dupont Circle	26	19%
Georgetown	51	36%
H Street	31	22%
Logan Circle	18	13%
(Non-Dupont Station Sample Sum)	*114*	*81%*
Type of Establishment:		
Food/Drink	69	49%
Retail	43	31%
Neighborhood Service	8	6%
Entertainment	2	1%
Other	6	4%
Unidentified	12	9%
(All Non-Food/Drink Sample Sum - excludes unidentified)	*59*	*42%*

Businesses know about CaBi. Figure 2.11 details business's awareness of CaBi's presence. The vast majority of businesses surveyed (88%) were aware of the CaBi system, demonstrating the system's visibility as a mode of transportation in Washington, DC. Nearly one-third (32%) of the respondents reported having used CaBi.

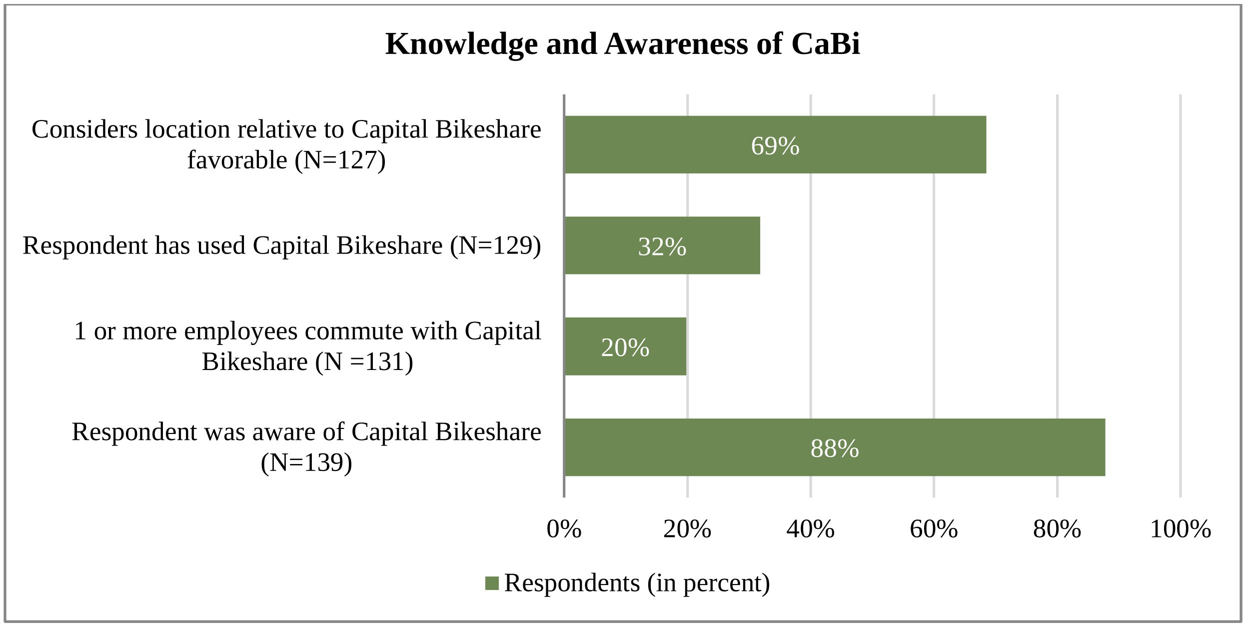

Figure 2.11: Knowledge and awareness of CaBi.

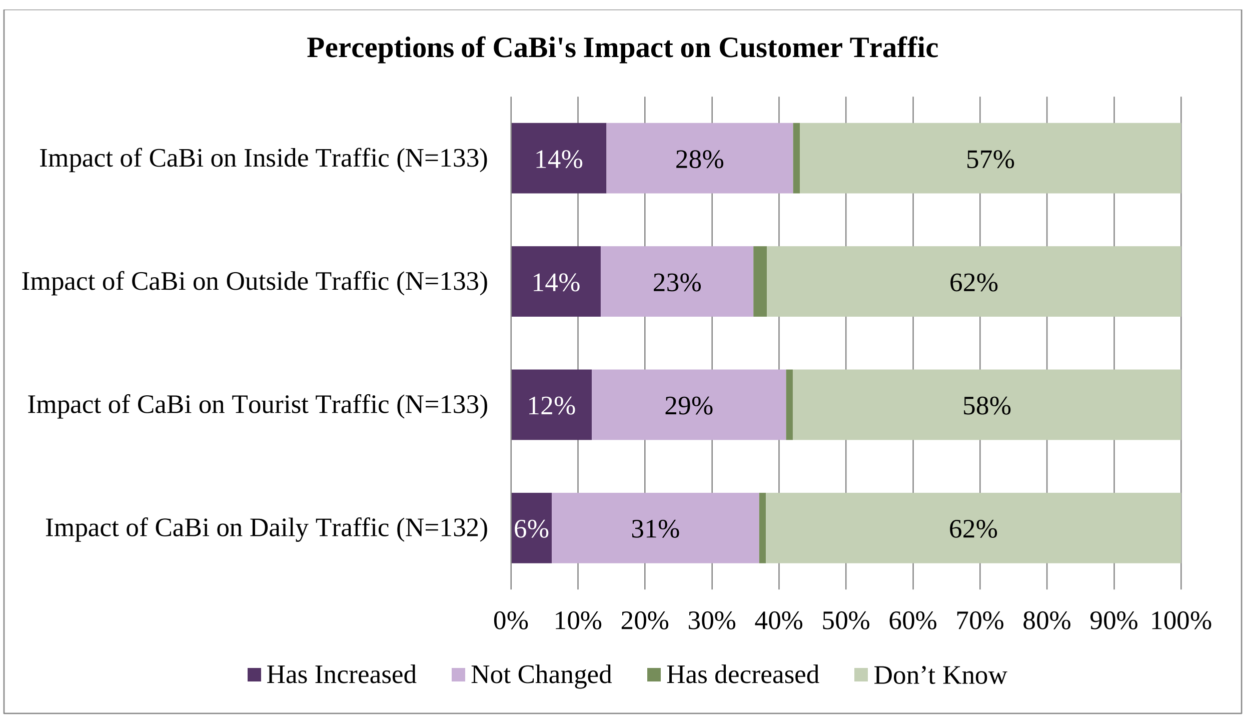

Figure 2.12: Perceptions of CaBi's impact on customer traffic.

Businesses see an increase in customer traffic because of CaBi. Figure 2.12 summarizes respondent opinions on whether the presence of bikeshare increased customer foot traffic within their establishment. Most respondents did not know if bikeshare had any effect on levels of customer traffic regardless of who it was (daily customers versus tourist customers) or from where the increase came (outside versus inside the neighborhood).

Businesses have a positive perception of CaBi and would like to see an increased presence near their businesses. Figure 2.13 describes respondent opinions on what effect bikeshare has had on their establishments and the neighborhoods they serve. While most businesses did not perceive a direct increase in customer traffic and revenue, 70% of businesses surveyed felt that CaBi had a positive effect on the neighborhood and 69% described their location in relation to CaBi as favorable.

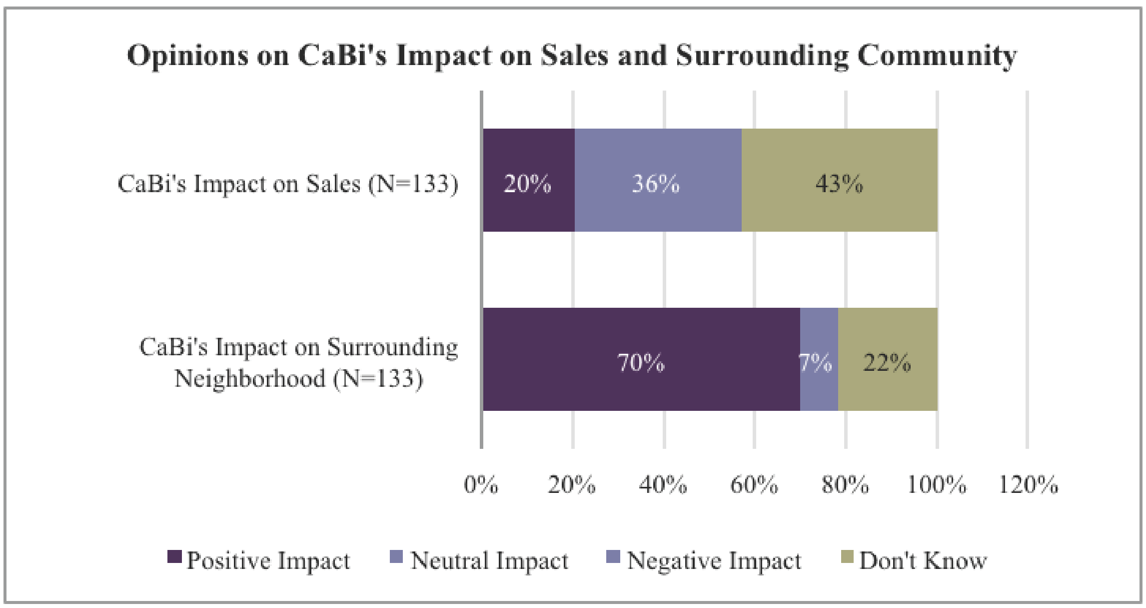

Figure 2.13: Opinions on CaBi's impact on sales and the surrounding community.

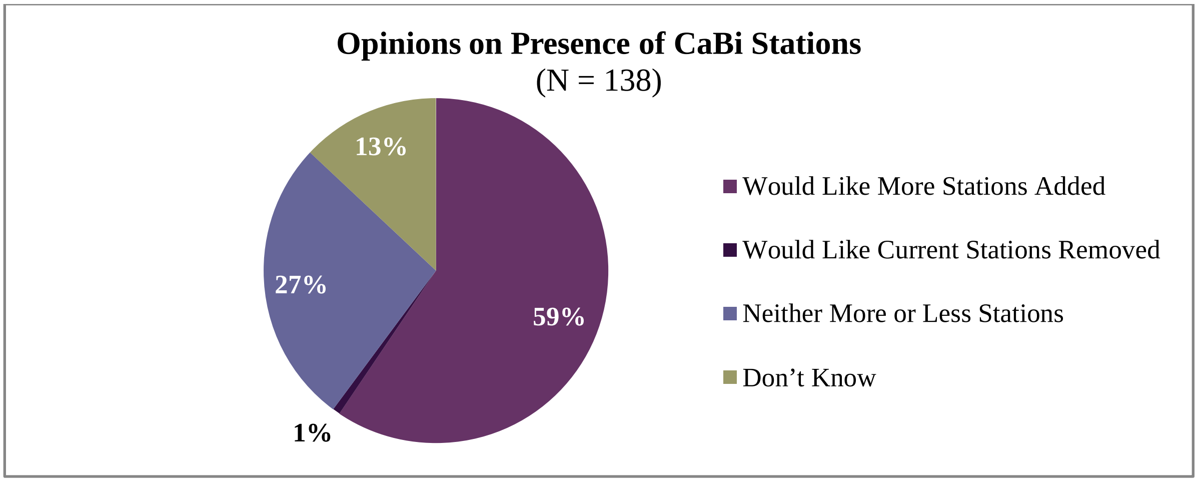

Figure 2.14: Opinions on the presence of CaBi stations.

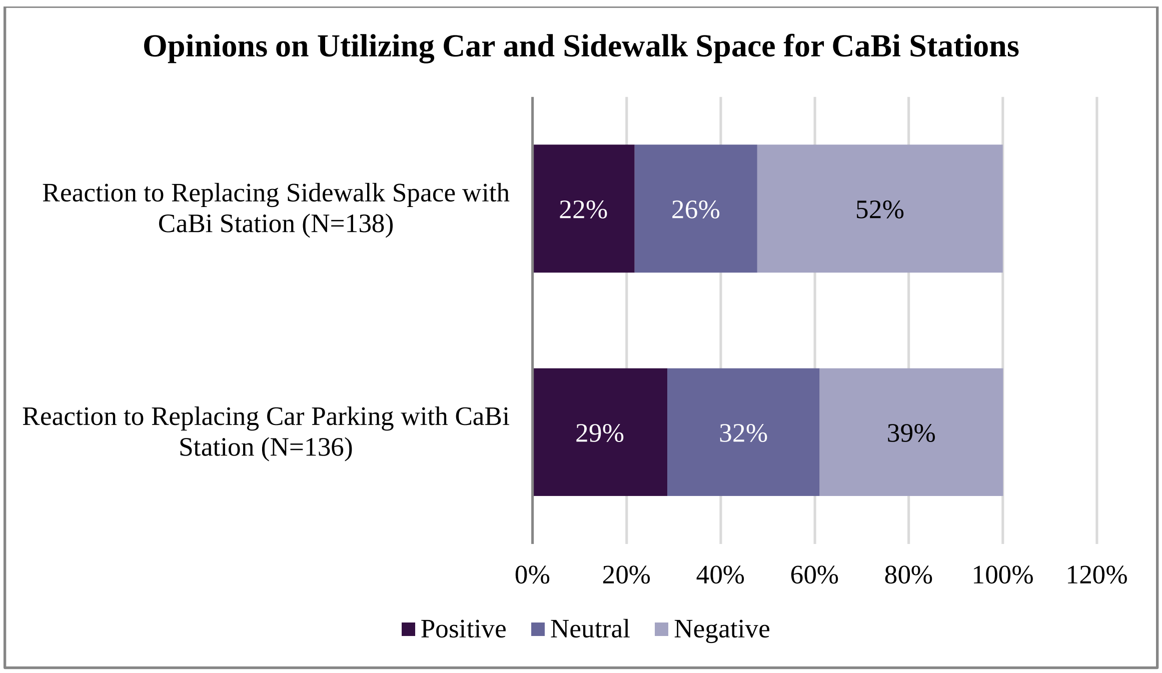

Figure 2.15. Opinions on utilizing car and sidewalk space for CaBi stations.

Business respondents were overwhelmingly positive about the presence of bikeshare stations and would like to see more added. Around 86% of respondents stated a positive attitude about the presence of stations within their neighborhood with 59% stating that they would like to see more stations added, as shown in Figure 2.14. Additionally, around 26% of respondents stated that they would be willing to offer discounts to patrons with CaBi memberships. Overall, these findings align with much of the previous research arguing that many businesses view bike

facilities as business amenities and are investing in methods to create a more pro-bike image to attract customers.

Business respondents were largely neutral or supportive about the idea of replacing car parking and were neutral about replacing sidewalk space with a new bikeshare station. Figure 2.15 shows opinions of businesses concerning the removal of both sidewalk space and car parking space to install new bikeshare facilities. Around 61% of respondents did not hold negative feelings about the loss of car parking space with 29% viewing such a change as positive. The removal of sidewalk space for bikeshare facilities had much lower support among respondents. Around 22% of responses viewed such a change as positive. These results would indicate that businesses are less willing to substitute sidewalk space than car parking space for bikeshare stations. These feelings may relate to the fact that the businesses that we surveyed were located in very walkable areas where sidewalks can become crowded with patrons.

CONCLUSION AND RECOMMENDATIONS

In sum, the separate surveys of CaBi users and businesses surrounding five stations suggest that CaBi can have a positive economic impact on commercial areas. We see that users often traveled to spending destinations and that planned spending most likely occurs within four blocks of the destination station. More than half of the surveyed users who planned to spend money also planned to return to the neighborhood on a daily or weekly basis; these responses suggest bikeshare users may be a consistent clientele. Arguably, though, the trips that would not have occurred without CaBi (induced trips) represent the true, additional benefit of a system. Just under 20% of the intercepted users would not have traveled to the neighborhood had the CaBi station not been located there. Moreover, over 80% of those making induced trips planned to spend money, and those induced trip takers tended to have higher household incomes. This suggests that installing new stations in commercial areas could generate new spending at surrounding businesses.

Installing new CaBi stations in a commercial area requires an understanding of business receptivity to those stations. The business survey results show that the vast majority of businesses think that CaBi has a positive impact on their neighborhood (70%) and that more than half (59%) would like to see more stations in their neighborhood. These findings align with the

general understanding that businesses support additional, efficient transportation options to their neighborhood in order to bring more customers. Building on this, less than half of the surveyed businesses oppose removing car parking spaces when installing a bikeshare station. Taken together, this general support of the bikeshare system combined with a majority that is either supportive of or neutral about removing car parking suggests that the business community may be receptive to new stations even when presented with public space tradeoffs. These findings may help local officials to assuage the concerns of businesses surrounding planned, new stations.

Perhaps most importantly, our results demonstrate that CaBi a) generates induced trips for new customers and b) saves time and/or money for the customers who would have traveled to the neighborhood regardless of the CaBi station. The commercial areas likely still experience a positive economic impact from the latter group, as the time and money saved by traveling via CaBi (instead of private automobile or even transit) can lead to additional spending at nearby businesses. Ultimately, we conclude that CaBi (and other, similar bikesharing systems) will likely produce positive and sustained economic benefits.

With this in mind, we recommend the following to local officials:

1. *Consider economic impacts when choosing station locations*. Based on the user intercept survey findings, bikesharing stations will attract customers to nearby businesses, with nearly nine in ten users living outside of the neighborhood planning to spend money. Moreover, we found that users are most likely to spend money within four blocks of the station. Keeping both of these points in mind can help convince reluctant businesses and property owners to host a new station.
2. *Encourage business owners to offer discounts to CaBi users*. The business survey results show that one in four businesses would be interested in offering discounts to CaBi users. By offering these discounts, nearby businesses can increase their chances of capturing the revenue from bikeshare users. These discounts only add to the money-saving potential that motivated one in four respondents to use CaBi.
3. *Communicate the true trade-offs of removing car parking to businesses*. The baseline CaBi station is the equivalent length of one or two car parking spaces. The number of customers who could park bicycles in that amount of space is much higher than the

number who could park using cars (Meisel, 2010). Not only are more bicyclists likely to use that space at any given time, but the turnover rate for bicyclists can be greater than for motorists. Therefore, local officials may communicate the number of additional customers who can arrive via bicycle in order to assuage business concerns. Additional research can hone in on the customer revenue differences between a single car parking space and a bikesharing station that takes up the same amount of space.

4. *Promote that bikesharing saves time as the fastest mode for certain trips*. Bicycling offers competitive travel times for many urban trips. CaBi usage fees align very well with this; the 30-minute "window" in which a user does not pay additional fees allows for trips upwards of five miles. For annual members in particular, the marginal monetary cost of a single CaBi trip is zero for trips under 30 minutes. When customers travel for free, they may be more likely to spend money at local businesses; when customers travel faster than other modes, they may spend more time in one business or visit more businesses.

3 BIKESHARING SYSTEMS SURVEY

Bikesharing systems have emerged in recent years as a low-cost and environmentally- friendly way to increase urban mobility (Vogel 2011). Users typically rent bikes for several different reasons: to bridge the gap between existing public transportation facilities and the user's end destination and to complete short, inner-city trips. Bikeshare user behavior is characterized by patterns of pickups and returns, and studies of multiple systems classify users into commuter, tourist, and leisure groups (Vogel 2011).

Modern bikesharing systems consist of automated, unstaffed stations situated on the sidewalk or in a protected part of the street. Bicycles are held in docks, and users can rent the bikes from a digital payment terminal located at each station (Borgnat 2011). Systems offer short-term daily and weekly rentals as well as monthly or annual memberships. Bikeshare pricing is designed to encourage short trips. For example, CaBi in the Washington, DC area charges an upfront rental fee ($7 for daily users, $75 annually), and trips over thirty minutes incur additional usage fees. The digital terminals also collect and transmit data about the arrival and departure activity at each station. Only a few bikeshare systems track movement through GPS units on each bike (The City of New York 2013).

The Balancing Problem

Bikeshare users typically rent bikes for short, one-way trips. This usage pattern can lead to systemic imbalances. For example, after the morning commute, most of the bikes will end up concentrated in employment areas near the city center, with very few remaining in residential neighborhoods. Bikeshare users experience the balancing problem when they want to rent a bike, but their origin station does not have any available bikes for rent, or when they want to return a bike, but their destination station is full (Vogel 2011, Borgnat 2011, etc). If bicycles or docks are consistently unavailable, bikeshare users could decide to stop using the system (Raviv, Tzur, & Forma, 2013, p. 188).

Multiple factors influence the spatial and temporal patterns of bikeshare usage, ranging from weather patterns and topography to street network patterns, land use, and the physical

surroundings of bikeshare stations. Bikeshare system operators have two basic ways to correct imbalances: 1) repositioning bikes within the system by moving them on vans, trucks or other vehicles; and 2) increasing system capacity by adding more stations and bikes in high-demand areas (Vogel 2011).

Capital Bikeshare Director Eric Gilliland stated that the centralized location of jobs and businesses along with higher elevations in the outer residential areas are primary drivers of CaBi's imbalance, which primarily affects people who incorporate CaBi into their commute. Potential users who wish to use CaBi to commute to work may encounter empty stations at the beginning of their commute, or find that their downtown destination station is full. Commuters who use CaBi to complete trips from other transport modes may also encounter empty bikeshare stations. Though CaBi was designed to complement other transportation modes, the system has emerged as a singular commuting option that fits with the environmentally friendly goals of the Sustainable DC Plan, which aims to increase biking and walking to 24% of all commuter trips by 2032 (Sustainable DC Plan 2013).

Purpose

Our report investigates Capital Bikeshare's balancing problem and explores ways to increase system capacity and enhance operational efficiency. We developed a three part approach that includes:

1. A survey of domestic and international bikeshare systems, to identify best practices and the severity of the balancing problem across systems.
2. An analysis of usage in the Capital Bikeshare system to identify determinants of imbalance that can guide potential solutions.
3. An in-depth analysis of one potential solution to the balancing problem: satellite stations, placed close to stations that are prone to being empty or full.

SURVEY: ANALYSIS OF INTERNATIONAL BIKESHARE SYSTEMS

We performed a survey to compile information about best practices regarding bikeshare balancing operations worldwide. There were three motives for this survey: 1) to provide insight as to how different systems balance their stations; 2) to develop recommendations for bikeshare systems tackling similar issues; and 3) to identify unique procedures worthy of further research. By examining common imbalance causes and mitigation techniques, we seek to gain a greater understanding of bikeshare imbalances.

Our decision to survey bikeshare systems around the world was motivated by a prior Virginia Tech study of Capital Bikeshare from 2011 (Virginia Tech 2011). The 2011 study focused on understanding overall system operations. Researchers categorized two tiers of bikeshare systems: 20 systems from which they were most interested in obtaining survey responses, and a second tier of 180 systems that were of lower priority. Using the OBIS handbook (OBIS 2011) as a guide, the 2011 research group then developed a list of 12 questions that addressed topics that included rebalancing, maintenance, internal business operations, marketing, and station siting. The researchers had the survey translated into French, Spanish, German, and Italian, and then disseminated it by email. When needed, the group also conducted the survey via phone interviews. The response rate was lower than expected, with a 20% response rate for top-tier systems, and a 1% response rate for second-tier systems. The 2011 research group's case study analysis incorporated findings from a total of eight bikeshare systems. The sample was overwhelmingly comprised of international bikeshare systems, as six of the eight systems in the sample were located outside of the United States.

Building upon the 2011 Virginia Tech Capital Bikeshare Study, we focused on balancing issues using similar methods. By narrowing the scope of the questionnaire, we hoped to discover more trends and lessons in balancing operations.

Methodology

To begin, we compiled an outreach list of national and international bikeshare systems from Internet searches and added corresponding contact information. Based on the methodology from Virginia Tech's 2011 study, we then split this directory into two categories in an effort to identify two sets of bikeshare systems. The first tier prioritized bikeshare systems from which we were most interested in obtaining information. One factor that went into prioritizing bikeshare systems was system size; we gave systems with sizes larger or comparable to that of Capital Bikeshare a higher priority. To do this, we gathered data on the number of bikes per system as well as the city's estimated population density. We also sought to sample from a diverse range of systems in terms of their business models (e.g. non-profit, for-profit, etc.). Finally, we sought to generate a geographically diverse sample of systems. Our second tier systems comprised bikeshare systems that were of varying sizes and age in terms of years in operation. The greatest limitation we faced involved our foreign language abilities, which were limited to French, Spanish, and German. However, the final outreach list consisted of 52 systems. Despite our foreign language limitations, these systems maintained geographic diversity (Figure 3.1). A table identifying the two-tiers of bikesharing systems can be found in Appendix D.

We developed a survey comprised of 23 questions that sought to collect best practice information regarding balancing operations (Appendix D). Questions related to system capacity and demand, the degree of the balancing challenge, the causes of the balancing problem, when balancing problems occur, operational strategies and operational resources for addressing the balancing problem. Native speakers then translated the questionnaire from English into French, Spanish, and German.

Outreach

We relied primarily on email for survey communications with our sample of bikeshare systems and initiated contact through customer service or media representatives whose email addresses were available on official bikeshare system websites. However, we also used secure online forms as a substitute when contact email addresses were not readily available.

The research group emailed or submitted a recruitment message to 52 bikeshare systems introducing the survey and its aforementioned goals. The language of the recruitment message depended on the bikeshare system's location. For systems in countries where English is not the primary language, we provided the questionnaire in the country's native language, as well as English. Each system was offered the option to submit their questionnaire responses via email as a Word document or through a web-based survey form available through Virginia Tech's survey website (survey.vt.edu). The online survey posed the same questions as the questionnaire attachment and was also available in English, French, Spanish, and German. 75% of respondents submitted their responses through the web-based survey. We obtained informed consent from respondents as required by the Virginia Tech Institutional Review Board. In almost all cases, the respondent was a member of the system's operations team. The respondents are listed in Appendix D.

Data collection was conducted between October 29, 2013 and November 29, 2013. The research group sent reminder emails to those systems that were initially contacted by email. Additional outreach involved making domestic phone calls (including Canada), and communicating through social media. On average, it took 8.25 days to receive a survey response. It took much longer for bikeshare systems to respond when the initial contact was made through an online form. The response rate for international systems was 16.2% and the response rate for systems within the United States was 66.7%. The overall response rate for the 52-system sample was 30%.

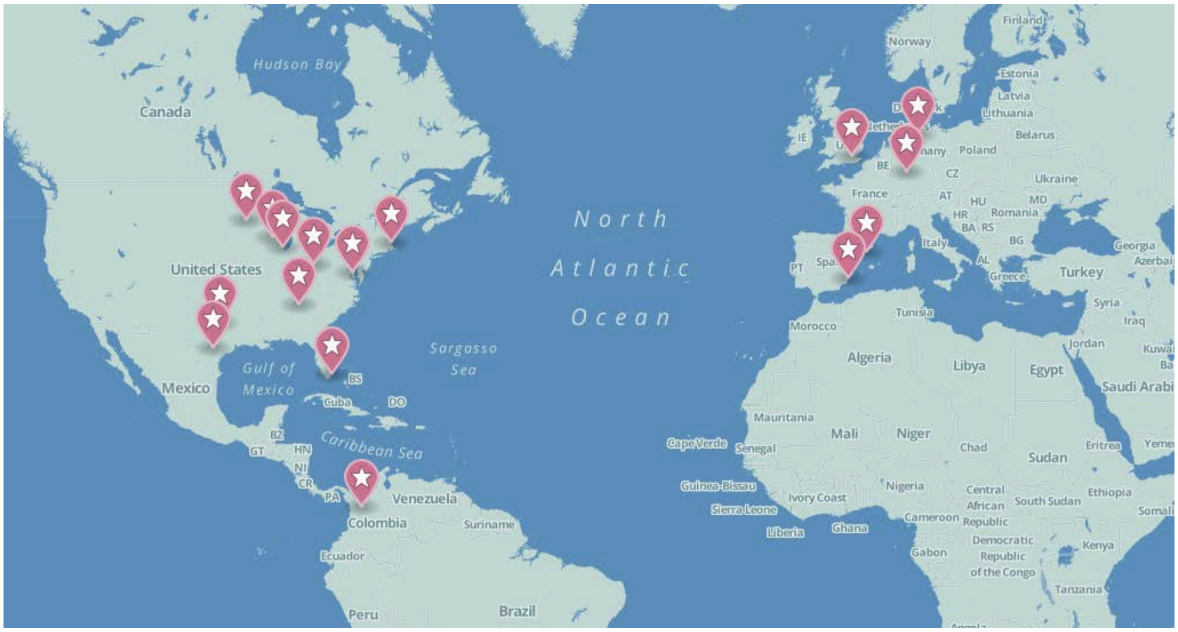

Figure 3.1. Locations of Responding Bikeshare Systems (mapbox.com).

Bikeshare System Respondents & Classification

Of the 52 systems, 16 systems completed questionnaires. Ten systems are within the United States, and 6 are located in other countries:

Bike Chattanooga Bicycle Transit System – Chattanooga, TN
Capital Bikeshare – Washington, DC
CoGo Bike Share – Columbus, OH
DecoBike Miami Beach – Miami, FL
Divvy – Chicago, IL
Fort Worth Bike Sharing – Fort Worth, TX
Hubway – Boston, MA
Madison B-Cycle – Madison, WI
Nice Ride – Minneapolis, MN
San Antonio B-Cycle – San Antonio, TX
Barclay's Cycle Hire – London, United Kingdom
BiCielx – Elx/Elche, Spain
Bicing – Barcelona, Spain
DB Rent GmbH – Hamburg, Germany
EnCicla – Medellín, Colombia
MVGmeinRad – Mainz, Germany

This was a significant difference from the 2011 Virginia Tech study, where six of eight systems were located outside the U.S. Each of the 16 bikeshare systems reported average weekday ridership, ranging from 100 to 45,000 rides per day. Because this survey focused on balancing systems during peak hours, we used weekday ridership as the most basic indicator of bikeshare

system size. To simplify the analysis, the 16 bikesharing systems were divided into three distinct groups based on the relative ridership activity of each system (Table 3.1): high (5,000 or more rides per weekday), moderate (1,000-4,999 rides per weekday), and low (less than 1,000 rides per weekday) levels of activity. These same 16 bikeshare systems were also divided into three different groups based on each system's perception of balancing challenges (Table 3.2): serious challenge, moderate challenge, minor/no challenge. The sample was distributed fairly evenly across the activity level categories, but less evenly across the balancing challenge categories with seven of the 16 systems in the moderate challenge group.

Table 3.1

Classification of bikeshare systems by weekday ridership.

Low Activity (<1,000 rides/weekday)	**Moderate Activity** (1,000-4,999 rides/weekday)	**High Activity** (>5,000 rides/weekday)
Bike Chattanooga	Bicielx	Barclay's Cycle Hire
CoGo Bike Share	DecoBike Miami Beach	Bicing
Fort Worth Bike Sharing	EnCicla	Capital Bikeshare
Madison B-Cycle	Nice Ride	DB Rent GmbH
San Antonio B-Cycle	MVGmeinRad	Divvy
		Hubway

Note. Responses to question 1 on questionnaire, "How many average rides per weekday?"

Table 3.2

Classification of bikeshare systems by perception of balancing challenge.

Minor/No Challenge	Moderate Challenge	Serious Challenge
Bike Chattanooga	Barclay's Cycle Hire	Bicielx
CoGo Bike Share	DecoBike Miami Beach	Bicing
Divvy	Hubway	Capital Bikeshare
Fort Worth Bike Sharing	Madison B-Cycle	DB Rent GmbH
	Nice Ride	EnCicla
	MVGmeinRad	
	San Antonio B-Cycle	

Note. Responses to question 4 (Likert Scale) on questionnaire, "To what degree is balancing a challenge or an issue for your bikeshare system?"

Perception of the balancing challenge

75% of bikeshare systems view balancing as a moderate to serious challenge (Figure 3.2). Over 30% of the 16 surveyed bikeshare systems view balancing as a serious challenge, and 44% of bikeshare systems reported balancing to be a moderate challenge. One quarter of the systems surveyed view balancing to be a minor challenge or no challenge. Thus, we found that most bikeshare systems in our sample experience challenges related to balancing.

We began the process of better understanding the relationship between bikeshare systems and their self-reported balancing problem by developing a profile of systems with the most severe balancing issues. Overall, systems reporting greater weekday usage also reported greater levels of concern regarding balancing operations. Figure 3.3 illustrates this trend. This pattern suggests that the larger a system grows, the more it should anticipate balancing issues.

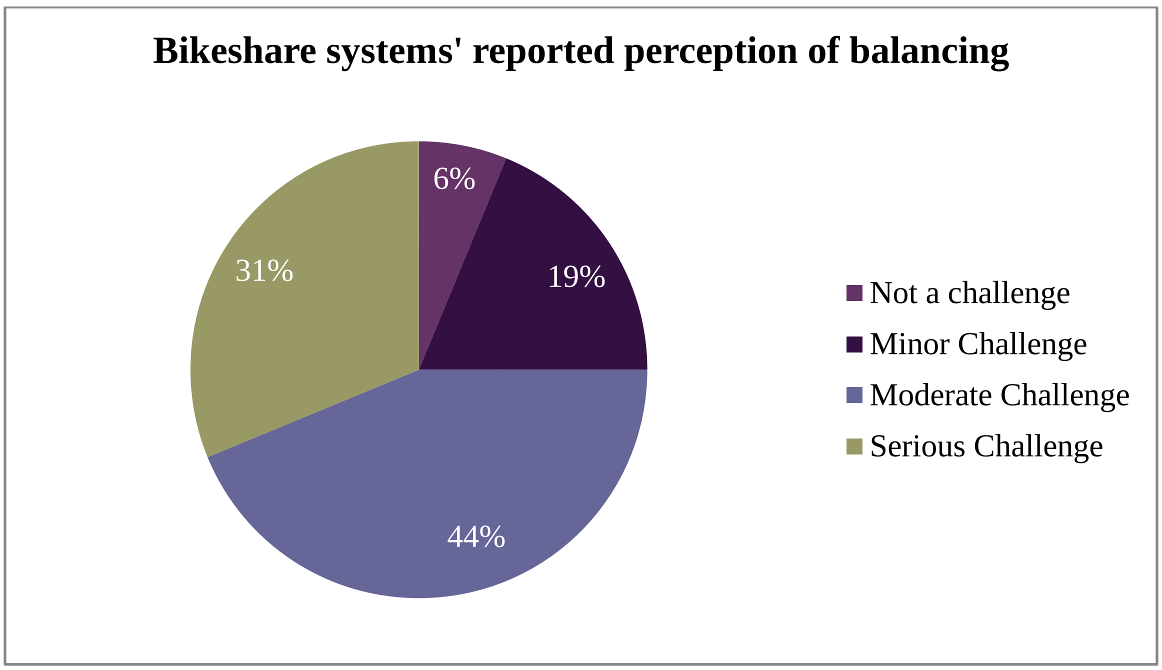

Figure 3.2 Responses to question 4 (Likert scale) on balancing questionnaire, "To what degree is balancing a challenge or an issue for your bikeshare system?"

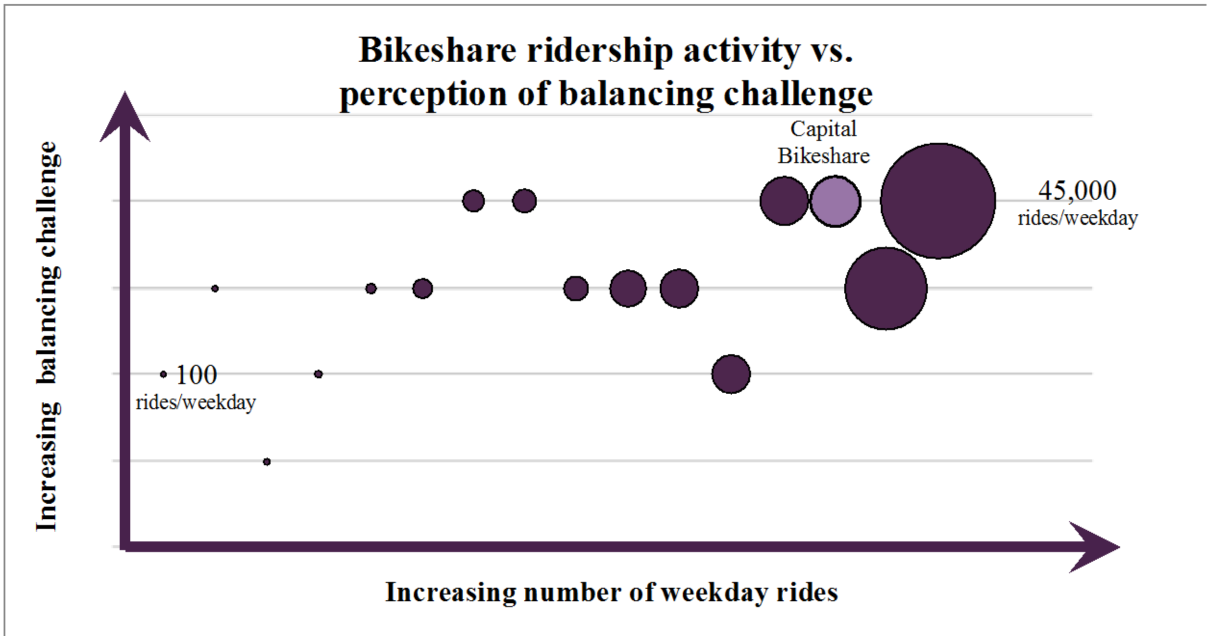

Figure 3.3 Relationship of 16 bikeshare systems showing size (ridership/weekday) vs. self-reported perception of bikeshare balancing and operations challenge. Capital Bikeshare highlighted for context; size of circle corresponds to system size.

BIKESHARE DEMAND AND CAPACITY

To gain a better understanding of the relationship between system characteristics and balancing operations, we first considered system size and system activity. This analysis looked at the reported number of docks for the smallest and largest stations of each bikeshare system as defined by activity level (Table 3.2). The trend is evident: systems with high ridership activity also have larger bikeshare stations (Figure 3.4).

Next we looked at the relationship between station sizes and each bikeshare systems' impression of the balancing challenge. This relationship is less distinct (Figure 3.5). The largest station average belongs to systems with moderate rebalancing challenges, not serious rebalancing challenges. This may suggest that systems with moderate rebalancing challenges avoid having serious rebalancing challenges by providing very large stations for areas with high ridership demand. It may also suggest that systems with moderate rebalancing challenges provide greater capacity (larger stations) relative to average daily ridership, or demand.

Moreover, by comparing Figure 3.4 and Figure 3.5, we hypothesize that some high activity systems may have moderate or no rebalancing challenges due to their high capacity of docks per station. In conclusion, our analysis of bikeshare demand and capacity suggests that larger systems tend to have more severe balancing challenges, though exceptions exist and the balancing challenge is not exclusive to high ridership systems.

Notable Responses

Barclay's Cycle Hire (London, UK) focuses considerable attention on operational improvements for rebalancing. Barclay's attempted to preemptively minimize imbalances during the station siting process. As a result of this tactical planning and their subsequent observations, Barclay's has set a minimum number of docks per station such that no future station within the City of London will have fewer than 25 docks.

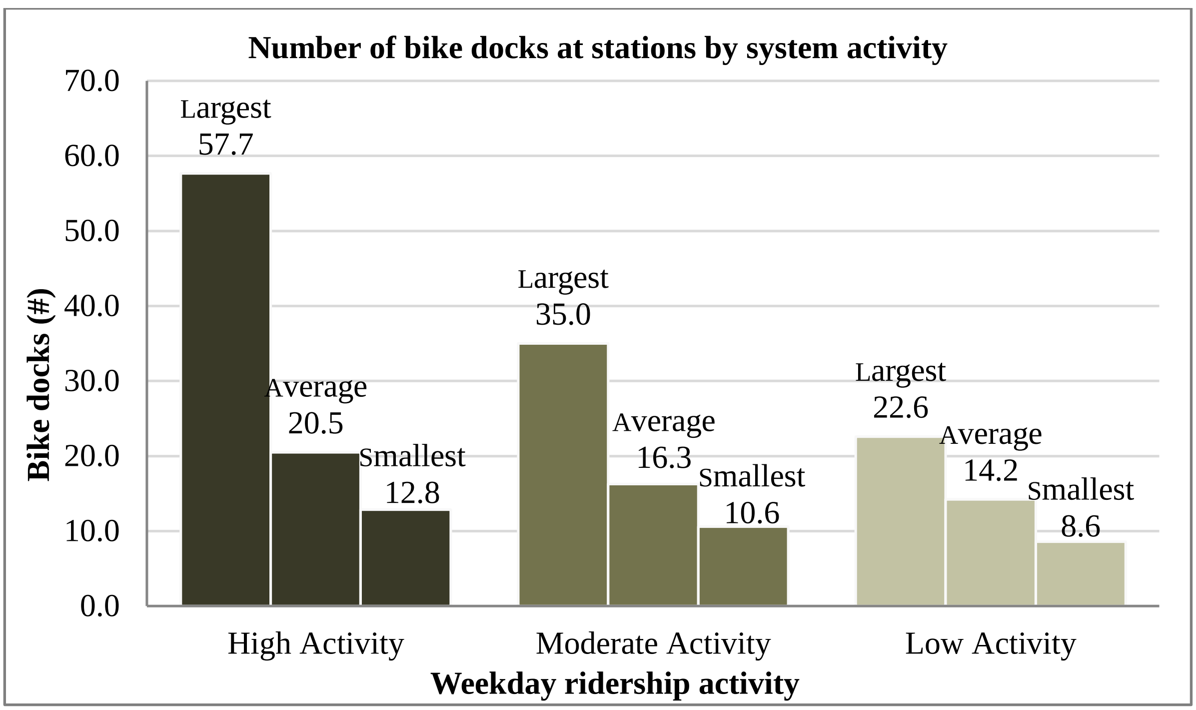

Figure 3.4 Responses to question 1 on balancing questionnaire, "How many docking spaces are in your bikeshare program's a) largest station b) smallest station c) average station?" organized by relative activity level.

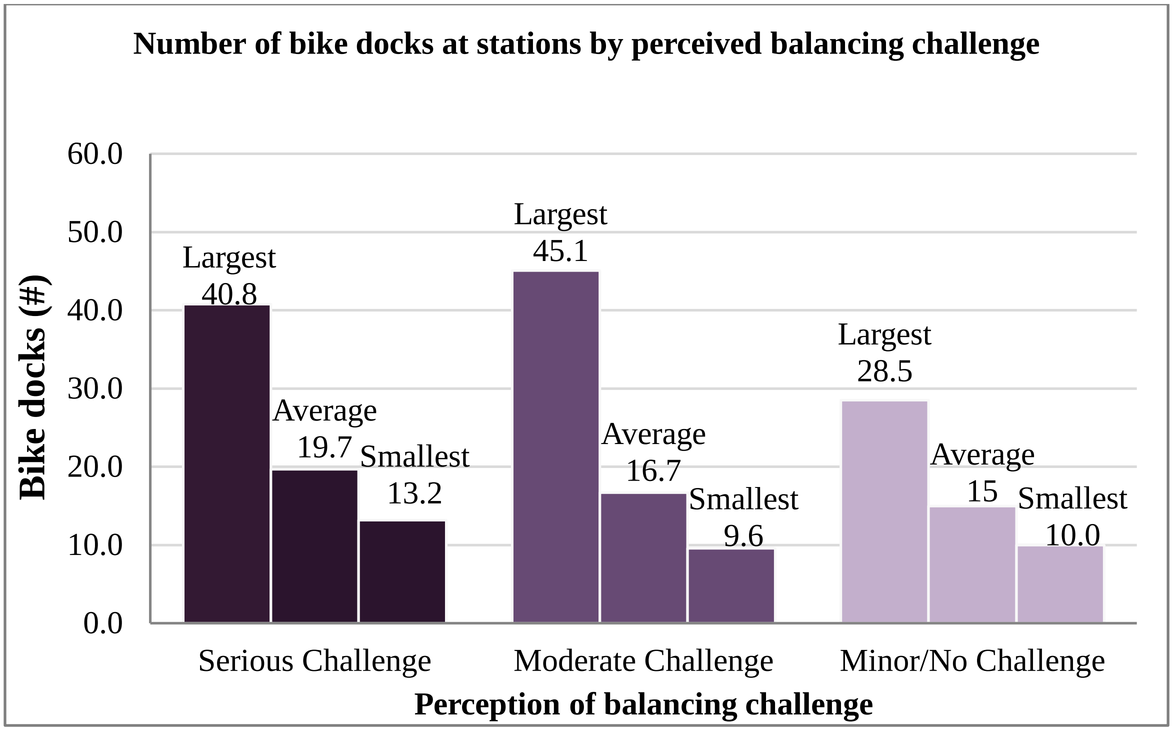

Figure 3.5 Responses to question 1 on balancing questionnaire, "How many docking spaces are in your bikeshare program's a) largest station b) smallest station c) average station?" Organized by degree of balancing challenge.

Peak hours

We examined the relationship between weekday peak hours and system activity level as well as degree of perceived balancing challenge. Overall, many bikeshare systems struggle to meet peak demand in the morning hours: one-half of the systems reported their highest daily usage before 09:00 (Figure 3.6 & Figure 3.7). Some systems reported that peak hours extended all afternoon and evening (between 12:01 and 21:00). One system considered late morning to be a busy cycling time, while no systems reported evening hours after 21:00 as peak hours.

High activity systems comprised 66% of systems that identify early morning hours as peak hours. Further, high activity systems made up 60% of those systems that identified the hours of 18:01-21:00 as peak hours. As with other modes of transportation, a heavily used bikeshare system may be expected to have a larger number of commuter-users, and thus stronger peaks during the morning and evening commuting hours.

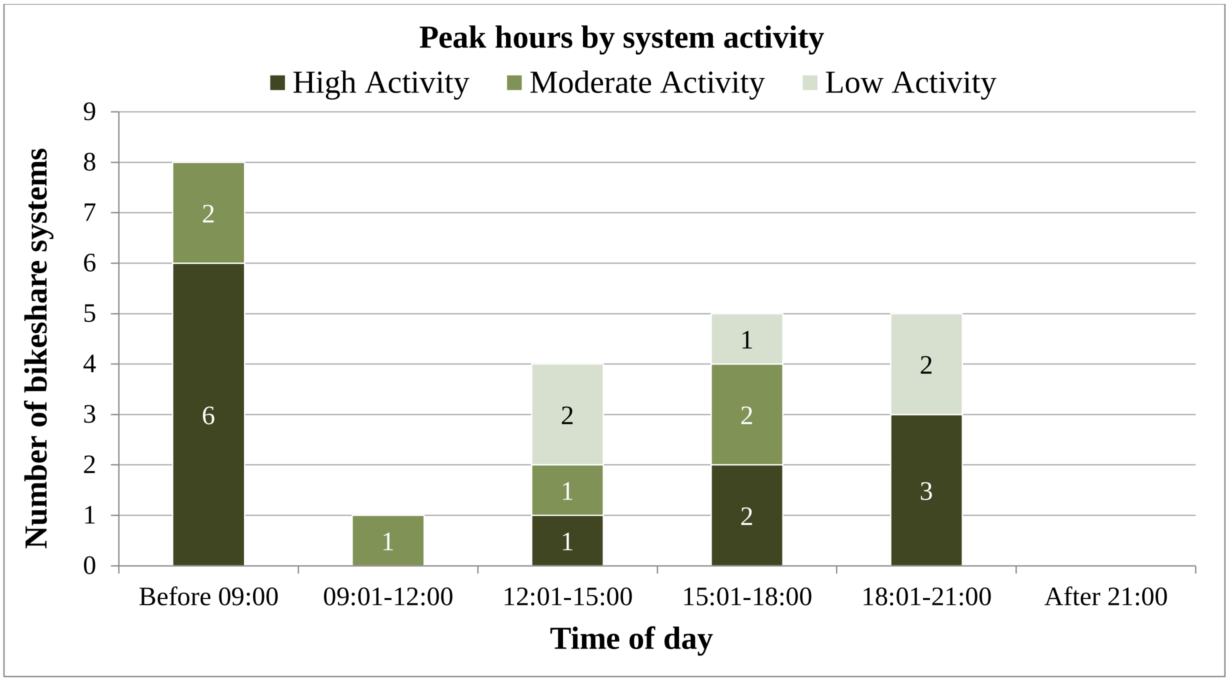

Figure 3.6. Responses to question 3 on balancing questionnaire, "At what time(s) does peak weekday usage occur?" Respondents selected all that applied. Systems organized by relative levels of system activity.

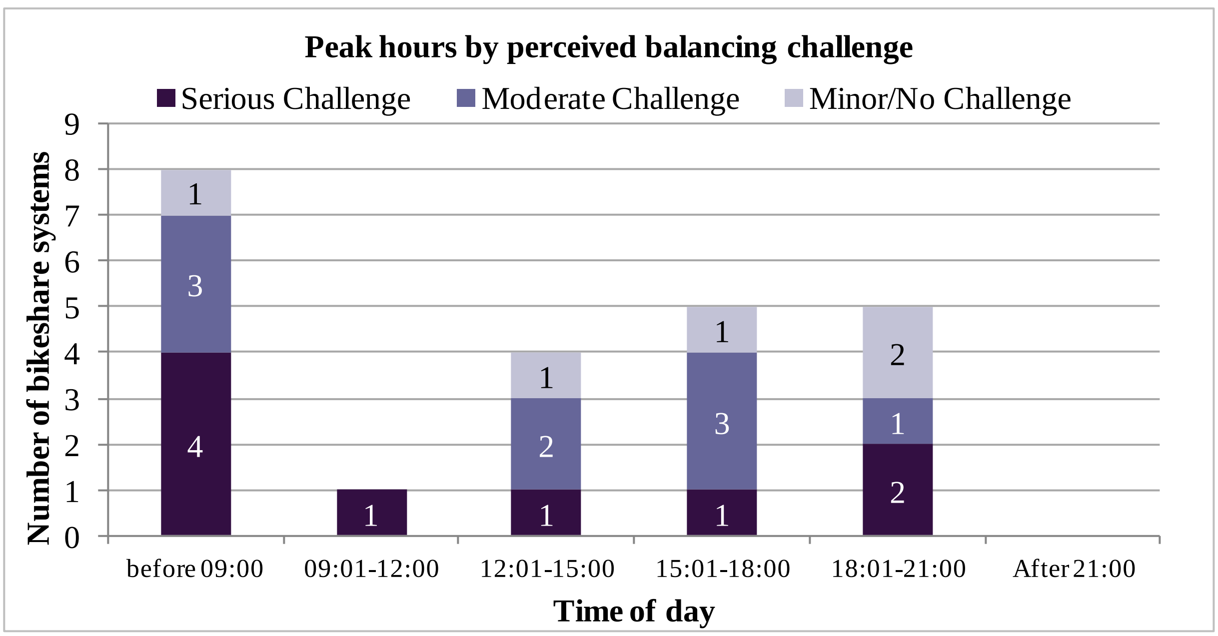

Figure 3.7. Same question as Figure 2.6. Organized by balancing challenge.

Moreover, it is not surprising that four of the five systems with serious balancing challenges reported early morning hours as peak hours. High activity systems selected more peak hours (ten responses from six systems) than moderate and lower activity systems (six and five responses

respectively). This indicates that high activity systems have many peak periods throughout the day. These multiple peaks may contribute to the balancing problem.

Notable Responses

Some bikeshare systems provided more detailed information about its peak hours. For example, 15%, or about 3,500, of Barclay's Cycle Hire's (London, UK) weekday rentals take place between 08:00 and 09:00, which indicates a very highly fluctuating bike distribution in a short span of time. Similarly, Divvy (Chicago, IL) reported that its most difficult time of the day with regards to balancing occurs during the morning and evening rush hours, when commuters arrive and depart downtown at approximately the same time.

CAUSES OF THE BALANCING PROBLEM

Next, our research group sought to directly evaluate the causes of the imbalance problem. We designed a multiple-choice question to solicit direct information about causes, including an "other" option with a free response. High activity systems identified a substantial number of additional causes of system imbalances that were not listed as options on the questionnaire (Figure 3.8). These additions include: *construction*, *rush hour*, *extremely high per-bike daily usage*, and *commuting patterns*. Only one moderate activity system went beyond the choices provided in our survey, while none of the lower activity systems selected "other". This suggests that as ridership activity increases, systems are exposed to and affected by a wider range of factors than smaller systems. Additionally, systems with serious balancing challenges found almost all of the issues presented to be a cause of balancing challenges (Figure 3.9). The one exception was that these systems did not attribute their issues to the street network.

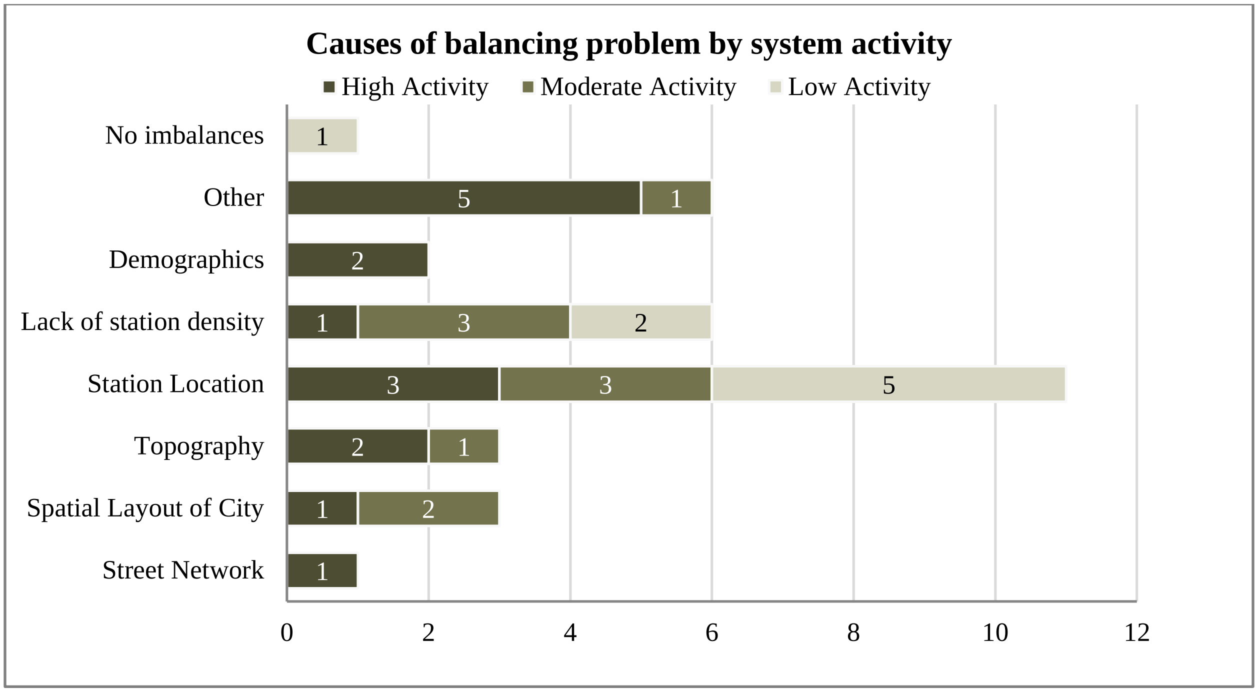

Figure 3.8: Responses to question 5 on balancing questionnaire, "What do you think causes the imbalance in your bikeshare system?" Respondents selected all that applied. Systems organized by relative levels of system activity.

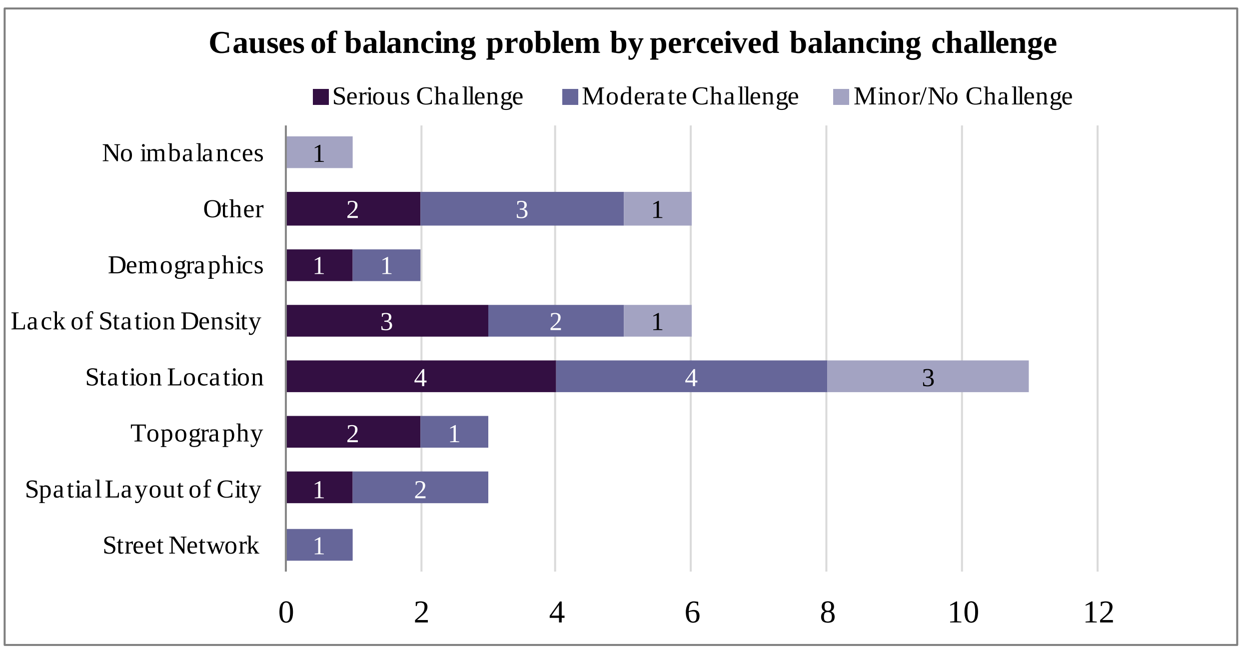

Figure 3.9: Responses to question 5 on balancing questionnaire, "What do you think causes the imbalance in your bikeshare system?" Respondents selected all that applied. Systems organized by perception of balancing challenge.

Notable Responses

Several systems elaborated on their answers. Barclay's Cycle Hire (London, UK) attributed part of its balancing problem to the Greater London Area's reliance on mainline rail stations, where the majority of bikeshare journeys begin. Mainline rail stations are located around the edges of London, which results in what Barclay's calls the "inevitable…areas of fullness in the City [central business district] and [mainline] Rail Stations with zero bikes for a short time." EnCicla (Medellín, Colombia) lists high automobile traffic during peak hours as a factor contributing to system imbalances. It is possible that automobile congestion results in slower rebalancing operations. Finally, Nice Ride (Minneapolis, MN) spans the two downtowns of Minneapolis and St. Paul, which are about 11 miles apart. Therefore, the system is not as dense as many of its peer systems. Rebalancing trucks may have a long distance to drive to a destination station, thereby increasing the travel time between stations and slowing rebalancing operations.

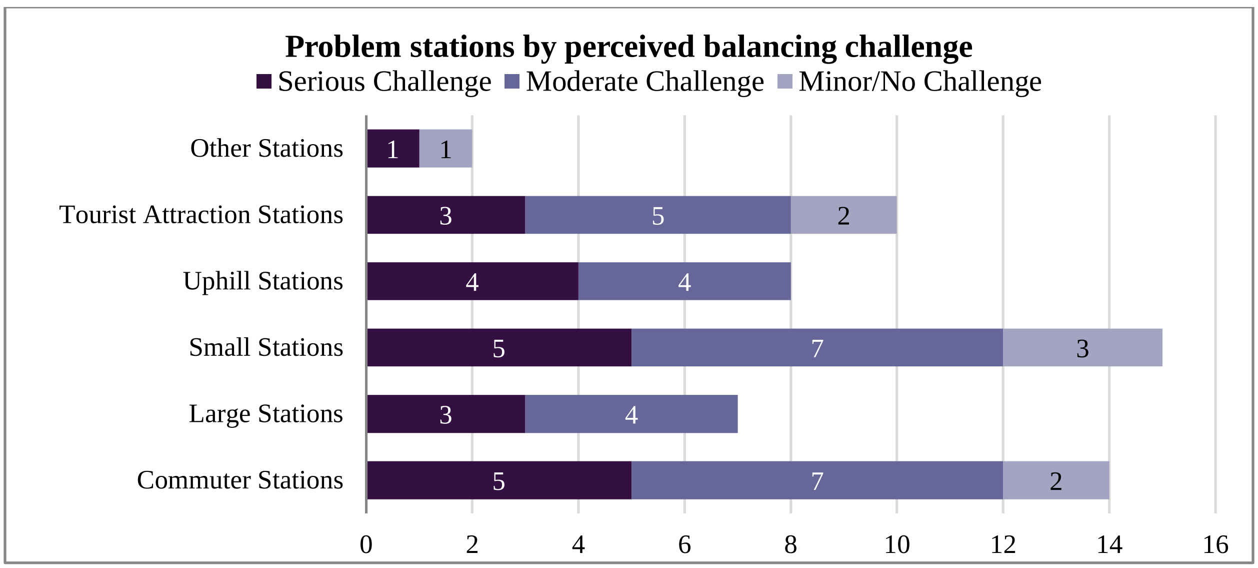

Figure 3.10: Responses to question 13 on balancing questionnaire, "What types of stations need rebalancing?" Respondents selected all that applied. Systems organized by perception of balancing challenge.

Problem Stations

We also investigated which types of stations have the biggest balancing issues (Figure 3.10). The responses to this question provide additional insight into causes of the balancing problem. Of the 16 surveyed bikeshare systems, 15 indicated that small stations cause the most balancing issues system-wide. Given this result, further study that identifies the challenges to expanding station

capacity could be instructive. If bikeshare systems are unable to increase capacity at existing stations, the use of satellite stations may be a potential remedy and is a strategy this report explores below.

Fourteen of the 16 systems in our sample consider commuter stations to be a source of their balancing issues. Commuter stations are those serving the primary commuter flow, from residential neighborhoods to the central business district in the morning. 10 of 16 systems considered stations with high tourist traffic to be challenging stations; however, the question did not indicate whether the problem varied between weekdays and weekends. We expect that tourist stations will vary in balancing needs and challenges depending on the city, time of the week, and time of year. Eight of the 16 bikeshare systems in our sample indicated that stations located at higher elevation are sources of balancing problems.

Notable Responses

Bicielx (Elx/Elche, Spain) indicated that significant places of attraction or high employment, such as hospitals and universities, make it nearly impossible to achieve the required service levels at nearby stations. EnCicla (Medellin, Colombia) reported similar problems, as university class schedules create patterns of high demand and instances of full and empty stations. Further, Bicing (Barcelona, Spain) reported that they must focus all efforts on the constant redistribution of bicycles because its users prefer to bike downhill but not uphill. Barcelona's topography contributes to this problematic ridership pattern, as the downtown is located in a basin with outlying residential areas at higher elevations (Lin and Chou 2012).

OPERATIONAL RESOURCES FOR REBALANCING

In this section, we focus on system operations, which is a strategy for rebalancing bikes. Bikeshare operations managers must decide which stations need to be rebalanced, what time they need to be rebalanced, which vehicles should do the rebalancing, and how many bikes should be placed at each rebalanced station (Raviv et al., 2013).

Operational challenges and resources

Bikeshare operations managers face a number of challenges, including highly fluctuating demand, the fixed locations of bikeshare stations, and vehicle routing (Lin & Chou, 2012; Vogel

& Mattfeld, 2011). The vehicle routing problem (VRP) relates to finding the shortest path connecting multiple locations with the same start and end point and involves complexities regarding vehicle and station capacity dynamics (Lin & Chou, 2012). The 16 bikeshare systems that responded to our survey identified some of the operational resources for rebalancing, including strategies, rationales, and technologies. We have highlighted common and noteworthy operations practices, which include rebalancing strategies and patterns for bikeshare employee practices, warehouse location and use, vehicle use, and technology for both public and non-public use.

Common rebalancing strategies

Bikeshare systems identified four common methods for planning and coordinating rebalancing efforts: (1) use of a central dispatcher to direct rebalancing staff, (2) real-time communication between rebalancing staff to coordinate which stations should be rebalanced, (3) predetermined routes for rebalancing crews, and (4) zones or territories for which rebalancing staff are responsible.

Coordination between rebalancing staff and direction from a central dispatcher are needed to handle unplanned responses to real-time system fluctuations. Low-activity systems may use these strategies because their systems are less complex than medium or high-activity systems. Geographic zones and pre-determined routes are planned operational activities and require staff to prioritize stations with the highest ridership demand. They are more commonly used by systems with moderate to high ridership activity.

Real-time operational activities	Planned operational activities
Central dispatcher	Geographic zones
Communication between rebalancing staff	Predetermined routes

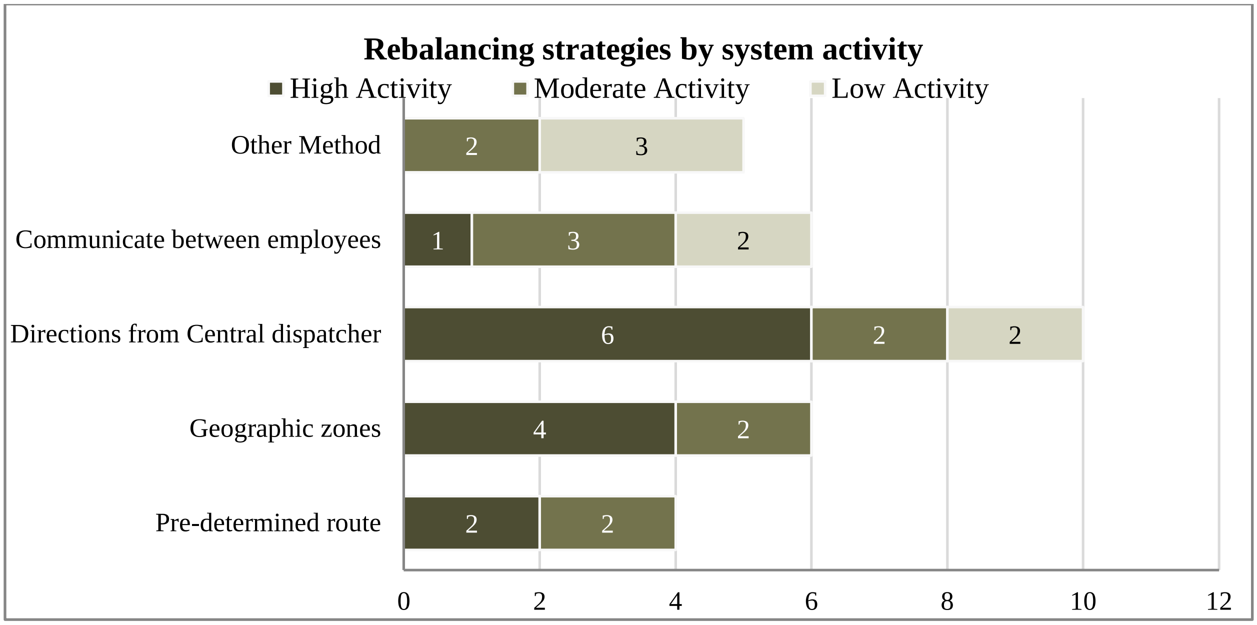

Figure 3.11: Responses to question 10 on balancing questionnaire, "What is the strategy for rebalancing bikes?" Respondents selected all that applied. Systems organized by ridership activity.

Figure 3.11 displays four rebalancing strategies identified by the survey respondents. All six high-activity systems utilize central dispatchers to communicate with rebalancing crews, and some low and medium-activity systems also use dispatchers. The only other strategy common among all three bikeshare system size classifications is communication among rebalancing employees. Only medium and high activity systems designate geographic zones. We postulate that as ridership patterns emerge and a system's footprint grows, rebalancing operations prioritize stations with frequent full and empty occurrences, rather than responding to the stations with the most recent outages. Similarly, only moderate- and high-activity systems use predetermined routes. Again, this suggests that increasing demand, larger coverage areas and the emergence of user patterns require more complex operations beyond coordination by a dispatcher or communication among rebalancing crews.

Most systems use a combination of rebalancing strategies, but no dominant pattern of tactics emerged. For example, London's Barclays Cycle Hire has an average of nearly 23,000 daily riders and uses geographic zones and a central dispatcher, but does not use predetermined routes. Barcelona's Bicing, with an average of 45,000 daily riders, uses predetermined routes in addition to geographic zones and a central dispatcher. More detailed information on ridership and station

capacity patterns could help explain why bikeshare systems decide to use certain strategies, such as predetermined routes or geographic zones.

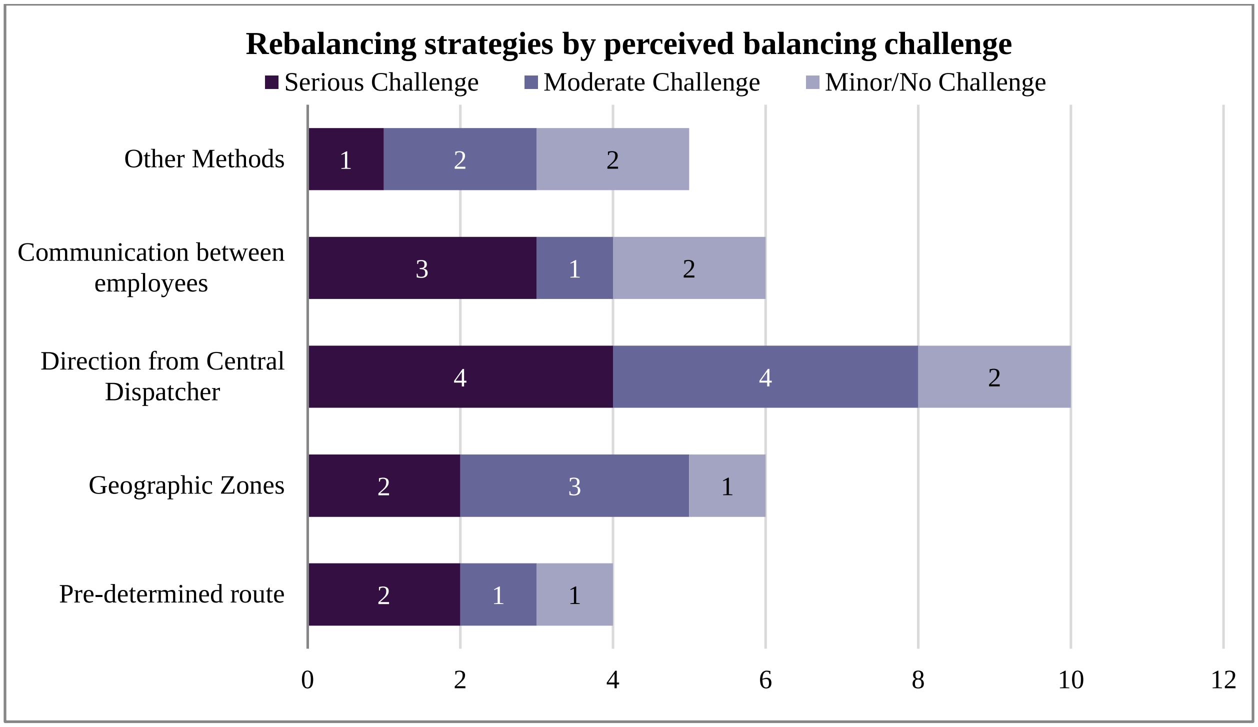

Figure 3.12: Responses to question 10 on balancing questionnaire, "What is the strategy for rebalancing bikes?" Respondents selected all that applied. Systems organized by perception of balancing challenge.

Daily rebalancing schedules

One of the primary decisions for a bikeshare operations manager is when rebalancing should occur. Static rebalancing is typically done at night, when bikeshare rentals are minimal. Dynamic rebalancing is done during the day, when the higher levels of usage result in a more highly fluctuating system (Raviv et al., 2013). Barclay's (London, UK) reports that three highly populated, predominantly upper-class residential districts (Chelsea, Kensington and Westminster) in Central London prohibit balancing activities between 22:00 and 8:00, which presents a significant challenge for meeting peak demand during the morning commute.

Two of the small systems in our sample with low average daily ridership numbers do not practice scheduled or daily rebalancing. Of the fourteen remaining bikeshare systems, five regularly rebalance during the day and at night (9pm - 4am), and all but one of those systems has high

activity levels. Another five low and moderate-level activity systems restrict rebalancing activities to daytime hours, typically immediately before, during, or after the morning commute. Four moderate to high activity systems did not clearly indicate the times during which they conduct rebalancing.

Determining when rebalancing is needed

As part of their rebalancing strategy, all of the bikeshare systems we surveyed actively monitor station capacities, but systems use a variety of tactics to determine the point at which a station needs rebalancing. Station capacity thresholds are the dominant tactic used by bikeshare systems to determine when stations need rebalancing. Some bikeshare systems impose time limits for how long a station can be full or empty before rebalancing, and a few other systems rely on the experience of their rebalancing crews.

Station capacity thresholds

Eight of the sixteen systems reported using a station capacity threshold, and three systems specified how full or empty they allow stations to become. For both Mainz's (Germany) MVGmeinRad and Fort Worth's (TX) Bike Sharing system, if a station is above 80% full or below 20% full, it is targeted for rebalancing. Bike Chattanooga (TN), on the other hand, allows stations to become completely full or empty before rebalancing. The other systems indicated that they relied on station capacity thresholds but did not clearly indicate the specific thresholds used.

Two systems, Bicielx and MVGmeinRad, reported using automated warning bells or alarms to indicate when stations are approaching a full or empty status. Bicielx attempts to keep either three bikes at each station or three docks available, and MVGmeinRad is alerted when stations approach 80-90% full or 80-90% empty. Bicielx and MVGmeinRad did not specify the mechanism of the alarm or who is alerted; this would be a topic for future study.

Unique practices: satellite stations

Several bikeshare systems reported unique practices to assist in their rebalancing threshold determinations. Fort Worth (TX) Bike Sharing indicated that if a full or empty station is near another station, they do not prioritize rebalancing because they expect the nearby station to

function as a satellite station. Users who originally sought to depart or arrive from the full or empty station may use the satellite station instead.

Time limits for full/empty stations

Two systems reported using time limits to determine when stations should be rebalanced. CoGo (Columbus, OH) sets a 90 minute limit for full or empty stations; they say that most instances of full or empty stations under 60 minutes in duration are resolved without intervention. Bicing (Barcelona, Spain) identifies the ten stations that have been full or empty the longest and also factor in logistically important stations and the time of day when deciding which stations to rebalance.

Employees

As indicated earlier in this report, rebalancing employees are responsible for repositioning bicycles so that specific stations have the desired mix of available bikes and docks. Employees drive vans or trucks, sometimes with trailers, to transport bikes from one station to another. In some systems, a central dispatcher directs employees to stations that need or will soon need to be rebalanced. In other systems, rebalancing employees rely on their own experience and real-time reports from other rebalancing employees to coordinate efforts among themselves. Rebalancing employees may also be assigned to geographic zones or predetermined routes. We asked bikeshare systems to reveal how many full-time equivalent employees are dedicated to rebalancing operations.

High activity systems and systems with serious rebalancing problems employed many more employees, as shown in the above Figure 3.11 and Figure 3.12. Barclays and Bicing, the two largest systems in terms of average weekday ridership, are the only systems that have staff solely dedicated to rebalancing. In all other systems, rebalancing staff performed other tasks in addition to their rebalancing-related activities, which are summarized in Table 3.3.

Table 3.3

Rebalancing-related activities.

Station maintenance	Bicycle maintenance	Rebalancing activities	Customer service
Station cleaning	Bicycle safety inspections	Pickup broken bicyles	Helping riders
Remove snow/ice in winter	Bicycle cleaning	Parking bicycles	
Grass mowing	Basic repairs	Bicycle pickups	
Station rebooting	Troubleshooting		

Rebalancing crew experience

Two systems reported that they rely on previously observed station patterns and the experience of their rebalancing crews to prioritize which stations need rebalancing. NiceRide (Minneapolis, MN) and EnCicla (Medellín, Colombia) both use real-time data to track station activity, but employees are familiar with typical ridership and station capacity patterns and communicate with each other to determine which stations should be rebalanced.

Warehouses

All of the 16 bikeshare systems we surveyed use warehouses as a base of operational activities. Warehouses provide storage for bicycles, station parts and rebalancing vehicles, space for maintenance equipment and operations, and a base for staff operations. Only Bicing, Barclays and Capital Bikeshare have two warehouses; all other bikeshare systems have only one warehouse.

Most bikeshare systems locate their warehouse within the bikeshare system's footprint to quickly and conveniently dispatch rebalancing vehicles to stations in need of bicycle repositioning. Madison's B-cycle is one exception, as its warehouse is located thirty miles away from the city. However, Madison's system shuts down during winter, so the warehouse is primarily used for off-season storage space. They did not indicate where they perform maintenance operations when the system is in service.

Some bikeshare systems reported their warehouse's relative proximity to stations. Divvy, Hubway and Capital Bikeshare, which are high-activity systems, reported that they are within the

system's footprint but are not centrally located. Of these three systems, only Divvy indicated the possibility of a new warehouse in the event of expansion. Several bikeshare systems viewed station docks as their primary bike storage location, perhaps suggesting that there was not a sizable reserve of bikes.

Notable responses: Depots and storage hubs

London's Barclays system has two depots, or warehouses to hold maintenance activities, staff, and vehicle storage. In addition to their depots, they also have three storage hubs that provide overflow or excess capacity around highly used stations to assist in daily rebalancing operations. One of the storage hubs is located within the City (central business district), while the other two are near busy mainline rail stations at the outer edges of London. At night, rebalancing staff reposition bikes from nearby full stations to the storage hubs, which opens up docks at the rebalanced stations for commuters.

Technology

We asked bikeshare systems to describe any technology used during rebalancing operations, whether the bikeshare system created the technology and whether it was publicly accessible. Responses varied in their level of specificity, making it difficult to identify broad trends. Six systems use proprietary software platforms or apps not available to the public. Most other systems utilized publicly available websites and mobile apps developed by the bikeshare system provider to monitor real-time station capacity activity. No systems reported using GPS to track individual bicycles, and only one reported the use of RFID technology to track bicycles. However, it is likely that most other systems use either RFID, GPS, or another tracking mechanism given that online tools to track system activity are common to bikesharing systems (Alta Planning + Design 2009).

Notable observations

Capital Bikeshare is the only bikeshare system that reported using GPS to track rebalancing vehicles. Bicielx developed a phone app that incorporates real-time alarms and ongoing repair work into its alerts.

FINDINGS

Our survey suggests that bikeshare systems worldwide appear to face similar problems when it comes to balancing operations. Balancing operations occur in all systems, yet the pressures felt from these balancing operations differ by system size. In general, the higher the ridership, the greater the balancing challenges.

System size and activity level, or capacity and demand, are primary drivers of the balancing challenge. Seventy-five percent of the systems we surveyed report a moderate to severe balancing challenge. As bikeshare systems expand their ridership and footprint, systems are exposed to and affected by an increasing range of factors that may include construction, traffic, and distinct ridership patterns that cause concentrated periods of high demand and low bike or dock availability.

Bikeshare systems, regardless of the degree of the balancing challenge, experienced balancing problems with small stations, commuter stations, and tourist stations. It is possible that small stations are not always distinct from commuter stations and tourist stations. The morning rush is the most difficult time to provide service to all users, as half of our respondents report peak ridership before 09:00.

Bikeshare systems with lower activity levels tend to use real-time operational activities, such as coordination between the rebalancing staff and direction from a central dispatcher. Systems with moderate or high activity levels tend to use planned operational activities, such as assigning geographic zones for rebalancing staff to monitor, or setting a predetermined route for rebalancing vehicles. However, no dominant pattern of operational tactics emerged from the survey responses.

There may be thresholds that trigger shifts from rebalancing as a *moderate challenge* to a *serious challenge*, or from *no challenge* to a *moderate challenge*. Thresholds may relate to rides per weekday—as our questionnaire explored—or perhaps to the average time a station is full or empty, the average ratio of full to empty stations system-wide, the number of active bikes in the

system, the number of employees dedicated to rebalancing, or even the warehouse placement. This study provides a basis for further exploring such thresholds.

PROMISING REBALANCING STRATEGIES

For systems with serious balancing issues, we recommend the following strategies to address balancing problems:

Storage hubs

For systems with extremely high-demand, high volume stations, and a large number of full or empty instances, the use of small storage hubs in a fashion similar to the Barclays system could alleviate balancing problems. The cost and scarcity of urban real estate near high demand stations may be a significant barrier to pursuing this approach. Further inquiry could identify how Barclays acquired or leased the property for the storage hubs, whether the hubs are housed in permanent facilities, temporary structures, or non-structured areas such as alleys. We suggest that bikeshare operations managers reach out to business improvement districts and other potential local partners to explore the possibility of storage hubs.

Employees dedicated only to rebalancing efforts

One way to increase operational efficiency is to train or hire staff that focus only on repositioning bikes. The only two systems that follow this practice have the highest average daily ridership of the sixteen systems in our sample. Bikeshare systems with a significant number of riders that value the system as a reliable commute option should consider this strategy to improve response time to highly fluctuating bike/dock availability.

Alerts

Two systems, Bicielx and MVGmeinRad, reported using automated warning bells or alarms to indicate when stations are approaching a full or empty status, but provided no information on how the alarm works, who is notified, or if bikeshare users have access to warnings or alarms. Further studies could investigate these aspects of rebalancing alarms.

4 ANALYSIS OF UNBALANCED STATIONS IN WASHINGTON, DC

Over the last several years, studies on bikeshare systems have increased as more and more data become available. While most of these studies look at patterns of usage and ridership factors, researchers have begun to tackle the issue of rebalancing. The focus of these studies has been route optimization (Lin & Chou 2012) and predicting outages and demand.

Missing from the studies and literature thus far is a consistent definition of system or station balance. Raw count numbers are used to discuss ridership and imbalance issues, but the literature does not address how to quantify imbalance or the severity of imbalance. Using consistent measures of balance and understanding the reasons why stations or systems experience severe imbalance can help bikeshare administrators and managers better evaluate the overall effectiveness of their systems. This information can help Capital Bikeshare and other bikeshare systems make more informed and cost effective decisions about station sizing, imbalance trends, rebalancing routes and the impact of other rebalancing strategies.

Our analysis consists of three sections. First, we used data on Capital Bikeshare to evaluate the imbalance occurring throughout the system, in order to better understand how to measure imbalance and the severity of imbalance. In the second part of our analysis, we utilized regression analysis to determine what factors outside of ridership may influence balance. Finally, in the third part of our analysis we assessed the potential effectiveness of a proposed remedy to the balancing issue, satellite stations.

Analysis of Capital Bikeshare's Imbalance

Trip history data

Capital Bikeshare makes a number of system metrics publicly available on its website, including a complete listing of the trips taken in the system (Capital Bikeshare 2013b). All rider information, except for their status as a casual (24 hour, three-day or five-day) user or a (monthly or annual) subscriber, is removed from the records. Other information for each trip includes the start and end stations, the start and end times of the trip (hour and minute), the duration (hours, minutes and seconds), and an ID number for the bike used. We aggregated this information to determine the number and duration of trips beginning or ending at each station for the entire system during the three-month span of May 1 through July 31 of 2013. These counts were calculated for the time period overall, as well as for the morning (8am - 11am) and evening (5pm - 9pm) weekday rush periods.

This time period was selected for several reasons. Over the last 3 years, May through October compose the highest usage months for Capital Bikeshare, with September and August being the highest months over the past two years respectively (Figure 4.1). Thus the time period of May through July represents a high ridership time period where outages and imbalance are likely to be problematic. Additionally, this study focuses on weekday balance issues and excludes all weekend activity. Weekdays exhibit more regular traffic characteristics and more severe outage problems. While it is likely that weekends have balance issues as well, the differences in travel patterns may skew our measure of imbalance. Thus we chose to focus on weekdays. A future analysis could examine weekend data to compare any differences in imbalance measures.

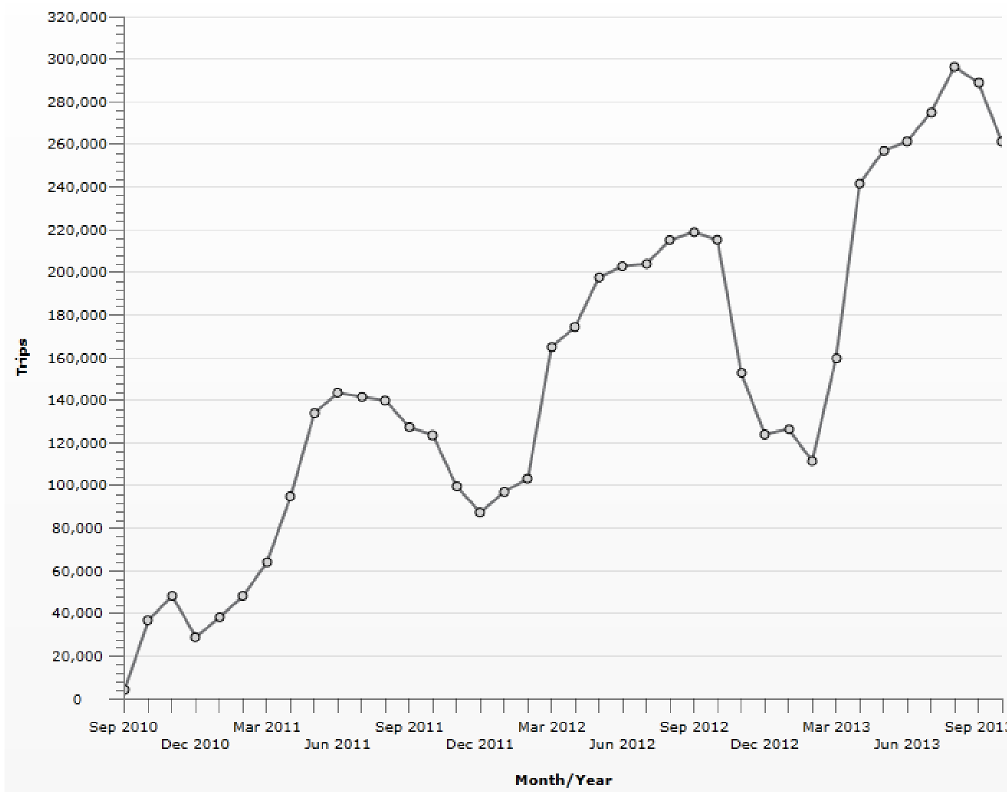

Figure 4.1: Capital Bikeshare Ridership by Month: September 2010 – October 2013

Note: Capital Bikeshare System Data Dashboard

Station Outage Data

Capital Bikeshare provides near-real-time station availability information (the number of docks and bikes available at each station) via a publicly accessible xml feed (Capital Bikeshare 2013c). The website *cabitracker.com* has been logging this information since April 2011, and uses it to present a variety of reports related to station capacity and outages (defined as instances when stations are completely empty or full). Users can download histories of station outages containing the station name, the times the outage began and ended, the outage's duration, and whether the station was empty or full (Cabitracker 2013). We aggregated this information to determine the number and duration of empty and full outages for each station, during the three month span of May to July 2013, again including only those outages that occurred on weekdays. These counts were calculated for the time period overall, as well as for the morning (8am - 11am) and evening (5pm - 9pm) weekday rush periods.

Analysis

Using the trip history data from the Capital Bikeshare dashboard and outage data from *cabitracker.com*, we analyzed all the trips and outages that occurred during May, June, and July, 2013. During the three month study period, the system had 557,628 bikes checked out, and experienced 60,666 outages. During the study period, 242 stations were active.

There was an average of 4,609 trips and 250.7 outages per station over this time period. The station at Massachusetts Ave. & DuPont Circle NW had 29,003 trips (combined arrivals and departures), the most of any station, and the station at 15th & P St. NW had the most outages during this time, with 1,384. Six stations did not encounter an outage, and the 5% least active (12 stations) had less than 123 trips each. Table 4.1 presents descriptive statistics of imbalance measures at the station level.

Table 4.1

Descriptive Statistics of Bikeshare Data and Imbalance Measures at Station Level

	Mean	Min	25%	50%	75%	Max
Outages	250.7	0	22	150	430	1,384
Trips	4609.0	17	981.8	3068.5	7042.0	29,003
Trips/Outage	45.9	8.5	15.5	23.2	44.0	580.0
Trips/Dock	247.3	1.5	80.7	205.6	364.3	993.2
Minutes Out	8792.5	0	1,395.3	7,014.5	15,463.5	28,779
% Time Out	9.6%	0.0%	1.5%	7.9%	17.0%	30.3%

The number of trips users can take is a function of the number of bikes in the system, which in turn is a function of the number of docks. For example if a system uses a simple ratio of 1 bike to 1 empty dock space available then a system with 1,000 docks will have 500 available bikes. If the system doubles its number of docks, and keeps the 1 to 1 ratio of bikes to available docks, the system now has 2,000 docks and 1,000 bikes. Holding other factors constant, more docks, and

thus more bikes, will result in an increase in trips. Indeed, trips and docks at the station level have a Pearson correlation coefficient of 0.8304 (Table 4.2).

Table 4.2

Correlation Coefficient for Trips to Number of Docks and Outages (Pearson correlation)

	Total Trips
Number of Docks	0.8304
Outages	0.6462

Therefore, to assess the trip load on a station independent of its size, we can compare the number of trips to the number of docks. This measure not only captures the operational load on a station, but also the wear and tear on the dock hardware, which may be useful from a maintenance perspective. Using this measure, during the study period the average station had 16.8 docks and a trips-per-dock ratio of 247.3 (Table 4.1).

Likewise, the number of outages on its own does not capture a station's imbalance problem. Similar to the relationship between the number of docks and trips, there is a relationship between the number of trips and the number of outages. Stations with more trips are likely to experience more outages, but this does not explain the degree of imbalance, nor does it illustrate how frequently outages are occurring. The Pearson correlation coefficient for trips and outages is 0.6462.

Since a primary goal of any bikeshare system is to provide as many trips as possible, dividing the number of trips by the number of outages can indicate the degree of imbalance. This can be interpreted as the number of trips served by the station before an outage occurs. The station level average was 45.9 trips per outage (Table 4.1).

Table 4.3

Load vs. Service Efficiency by Quartiles

		Service Efficiency (Trips/Outage)			
		<25%	25%-50%	50%-75%	>75%
Load (Trips/Dock)	<25%	2	5	17	36
	25%-50%	3	17	20	20
	50%-75%	25	18	15	2
	>75%	30	21	9	2

The overall trend that emerges is that as load increases efficiency decreases (Table 4.3). This is an important relationship that stresses the role that ridership plays in station and system balance, and suggests that a perfectly self-balancing system is rare. In doing this comparison we find that there are 11 stations in the 75th percentile or higher in terms of load that are also in the 50th percentile or higher in terms of efficiency (Figure 4.2).

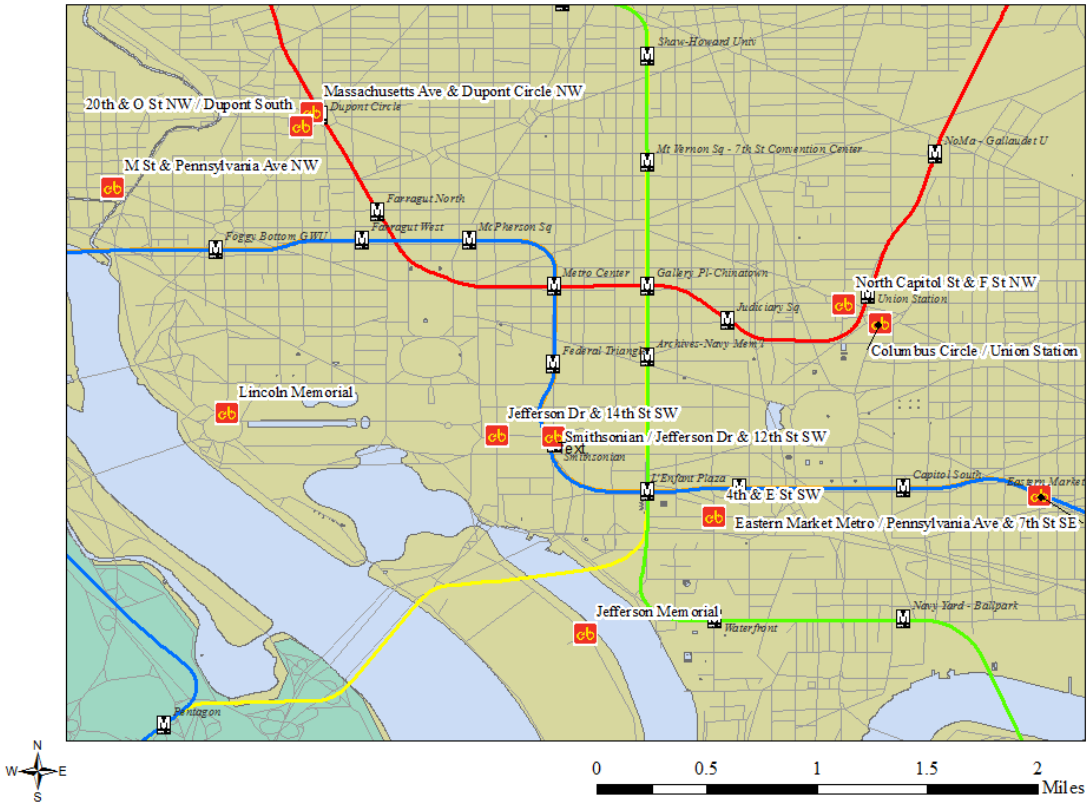

Figure 4.2: Best Performing Stations. There are 11 Stations that are in the 75th percentile in terms of load and who are also in the 50th percentile or better in terms of efficiency.

We argue that rebalancing is not unique to bikesharing and that most modes of transport use some form of rebalancing. For example, subways commonly run more trains into the city during the morning rush hour, and more trains out of the city during the afternoon rush hour. During the day and evening periods trains are dispersed to where they will be needed later, a type of rebalancing. The same is true for buses as well. On roadways, local streets and some expressways add lanes for peak travel flows in the peak direction, thus facilitating peak flows by adding capacity. Thus, while using route optimization techniques and technology to rebalance and shuttle bikes to and from stations can increase efficiency, systems can also manage and improve efficiency by adding to and improving their infrastructure in a manner analogous to these other transportation modes.

The number and size of stations are key infrastructure components for bikeshare systems. By comparing our efficiency measure to station size, characterized by the number of docks, we can identify potential areas for infrastructure improvements. Table 4.4 illustrates this comparison, but instead of using quartiles for the number of docks, station size is categorized by common dock numbers.

Table 4.4 shows that small stations (stations with < 13 docks) perform slightly above average in terms of efficiency. However, we find that stations sized between 15 and 20 docks have efficiency measures below 50% of the mean more often than have above the mean. The largest stations have efficiency numbers near the center of the distribution, tending not to have extremely high or low efficiency.

This stands in contrast to the system survey findings presented above, which indicated small stations are problematic. However, it could be that the smallest stations in our sample may have high efficiency numbers because some of them are in low demand areas. As shown in Table 4.3, low trip load on a station is related to higher efficiency. Most stations are in the 15-17 dock range: the large numbers of high and low efficiency stations suggest that many of these stations are inappropriately sized compared to others in the system. The additional capital investment involved in installing a larger station means that most of them are in high-demand areas, which may mean more effort was put into sizing them appropriately, leading to efficiency numbers closer to average levels.

This analysis highlights the fact that many stations may have too few docks. Increasing dock spaces will decrease the load measure, and in doing so, we can anticipate a resulting increase in efficiency based upon the relationship between efficiency and load described above. However, there is the potential for induced demand that may negate the benefits of increasing station size.

Table 4.4

Station Size vs. Efficiency by Dock Sizes and Quartiles

		Service Efficiency (Trips/Outage)			
		<25%	25%-50%	50%-75%	>75%
Docks	<25%	2	5	17	36
	25%-50%	3	17	20	20
	50%-75%	25	18	15	2
	>75%	30	21	9	2

REGRESSION ANALYSIS: WHAT INFLUENCES IMBALANCE?

The above analysis gives a basic understanding of how station size and demand are related to outages, but it fails to identify other characteristics that may influence station efficiency and balance. The following regression analysis uses each station's trips per outage as the dependent variable, along with the following independent variables: number of docks, population, distance to the nearest Metrorail station, housing units per acre, employment units per acre, street network connectivity, percent of residents with no cars, median income, absolute difference in elevation, and percent of casual trips.

These variables were selected based upon their potential impact, both positive and negative, on station efficiency. Small stations, commuter stations, and uphill or downhill stations were the top three most common responses for types of imbalanced stations according to our system survey results discussed above. So we included variables that could test for those characteristics: number of docks, housing units and job units per acre and difference in elevation. Additionally, the variable for distance to Metrorail was included to see how well stations connected to transit and the measure for street network connectivity was included to examine the impact of the street grid on efficiency. Additional demographic variables were included, as described below.

For this analysis we performed a stepwise regression. This was done because this analysis is exploratory in nature regarding the causes of imbalance. A stepwise regression is a strategy that may be employed when there is little theoretical or empirical guidance for model specification. An important limitation of stepwise regression is that it allows computer software to determine inclusion and exclusion of variables in the final model based on a set significance threshold ($p<0.1$ in our case). In addition, it is sensitive to the order in which variables are considered and is a form of data mining that makes accurate inference difficult (Wooldridge 2009). Thus, our analysis is a first attempt at modeling station efficiency in a multivariable regression, but future studies should seek guidance from theory and existing literature to obviate use of the stepwise technique.

Geography and Land Use Data

After geocoding the locations of 248 stations in the District of Columbia, Arlington, and Alexandria via data provided by Capital Bikeshare, we collected a number of environmental, land use and demographic variables and associated these variables with the stations using GIS. These variables were formed using data from the US Census Bureau, the United States Environmental Protection Agency's (EPA) Smart Location Database, and the US Geological Survey.

Table 4.5

Descriptive Statistics of Independent Variables &Pearson Correlation Coefficient with Station Efficiency Measure

	Min	Max	Mean	Standard Dev.	Corr
Number of Docks	9	41	16.80	5.80	-0.056
Population Density	0.83	219.11	30.60	31.32	-0.138
Distance to Metrorail (ft.)	44.95	1187.56	378.96	227.82	0.133
Housing Units/Acre	0.02	148.34	17.85	20.68	-0.132
Job Units/Acre	0	519.94	845.89	125.28	-0.118
Street Network	19.41	410.19	146.74	76.56	0.136
%Population with No Cars	0	0.9	0.30	0.22	-0.208
Median Income	0	167019	74999.33	40850.13	-0.016
Difference in Elevation	23	215	84.56	40.61	-0.015
%Casual Trips	0.03	0.81	0.18	0.14	0.006

To consider the potential impact of topography and, in particular, the issue of uphill and downhill stations, US Geological Survey elevation data were added to the GIS map. Using GIS, we calculated the maximum and minimum elevation points within a one-half mile buffer of each station, and subtracted the minimum from the maximum. The size of this difference between maximum and minimum elevation around each station provides a measure of the hilliness of the surrounding area.

Proximity to Metrorail stations and the overall level of transit service around the Capital Bikeshare station is likely to affect demand and outages. For Metrorail proximity, we measured the distance from each Capital Bikeshare station to the nearest Metrorail station. For transit service frequency, we utilized a metric from the EPA Smart Location Database, which provides a measure of rush hour transit service frequency for every census block group. To derive their metric, EPA analyzed transit data to calculate the frequency of service for each transit route during the weekday evening rush hour with stops within 0.4 km (0.25 miles) of each census block group. We associated each Capital Bikeshare station with the total aggregate service frequency index for the census block group in which it was located.

To evaluate the potential impact of the nature of the street network, we used an urban design metric from the EPA Smart Location Database. The metric shows street intersection density and is weighted to reflect connectivity for pedestrian and bicycle travel. The statistic is useful for testing our hypothesis that, as in the realm of walkability, a Capital Bikeshare station in an area with a more concentrated street network will be busier than others and could consequently experience more severe imbalance.

Using trip history data from Capital Bikeshare, we calculated the percentage of "casual" (one-day or three-day membership) users for each station. Not surprisingly, the stations with a high proportion of casual users were clustered along and around the National Mall, Tidal Basin, and related national monuments. This variable serves to distinguish 'tourist' stations that may not follow the commute-centric patterns seen in residential or business districts.

To evaluate the impact of land use on the balancing problem, we incorporated a number of metrics, again from the EPA Smart Location Database. These measures included housing units per acre, jobs per acre, and total activity (jobs + housing units) per acre within each census block group, as calculated by the EPA using a variety of data sources. We also calculated the ratio of housing units to jobs as a measure of the mix of land uses, where values close to one indicate a near even mix of residential land uses and commercial ones.

Additionally, the regression includes several variables based upon US Census Block Group data, including population density, median household income, and the percentage of zero-car households. These variables measure a number of demographic characteristics that may influence station imbalance.

Regression Results

Table 4.6

Regression Results for Significant Variables (+: positive coefficient; -: negative coefficient)

	Overall	Morning (8:00-11:00)	Evening (5:00-9:00)
Number of Docks		+	
Distance to Metrorail (ft.)	+		+
Job Units/Acre		-	-
Street Network	+	+	+
%Population with No Cars	-	-	-
Median Income		+	
Difference in Elevation		-	-

For the overall station efficiency measure, the stepwise regression (Table 4.6) finds several variables significant at the 90% and 95% confidence level ($R^2 = 0.1051$, $F(10, 231) = 2.71$, $p = 0.0036$). Because of the exploratory nature of our model, we only present in summary form the signs of the coefficients. Distance to the nearest Metrorail station and street network connectivity show positive correlations, and the percent of the population without a car has a negative correlation.

The distance to Metrorail correlation indicates that as a station moves farther away from a Metrorail station, the station experiences an increase in efficiency. This is the opposite of our hypothesis, but it may be explained by station demand. As the distance to the Metrorail increases and a station becomes less useful for making transit connections, users may be more likely to arrive and leave a neighborhood using the same transportation mode which would help to keep the station balanced.

According to the regression results, as street network connectivity increases, stations also exhibit higher efficiency measures. This suggests that stations situated in neighborhoods with dense

street networks are more well-balanced. It may be that the easier it is to access a station, the better the balance at that station.

The final variable that was significant for the overall time period is the percentage of the population that do not own cars. As that percentage increases, there is a decrease in efficiency. This suggests that stations located in areas with a high percentage of residents without cars could also experience a higher load, and thus lower efficiency measures.

Morning and Afternoon Rush

We performed two additional regression analyses, using data from only the morning rush period from 8:00am to 11:00am and from only for the afternoon rush period from 5:00pm to 9:00pm. The morning rush regression identifies six significant variables at the 95% confidence level (R^2 = 0.2173, $F(10, 227) = 6.30$, $p < 0.0001$). The afternoon rush finds five significant coefficients at the 90% and 95% confidence levels (R^2 = 0.1461, $F(10, 231) = 3.95$, $p = 0.0001$).

The variables for street network connectivity and the percentage of residents without cars continue to exhibit a similar influence as in the overall analysis over both time periods. Additionally, difference in elevation and job units per acre have negative coefficients for the morning and afternoon rush but neither are significant in the overall analysis. This may be explained by the difference in commute patterns during peak and non-peak periods. During both the morning and afternoon rush periods, stations in more central locations experience heavy demand. In the morning these stations have a high level of arrivals and in the evening a high level of departures. While residential locations exhibit the opposite trend, the intensity of the demand is more spread out. This may explain the negative relationship between stations with higher jobs per acre and efficiency. For the difference of elevation it is possible that these same areas, notably the central business district, are located downhill.

Interestingly, station size is only significant in the morning rush time period, while the distance to Metrorail is significant only for the afternoon time period. The reason for this difference likely occurs due to the differences in travel patterns for these time periods. With heavy ridership occurring in a much shorter time frame for the morning commute, it follows that station size

would play a larger role in efficiency. Larger stations hold more bikes and have more docking spaces for riders to drop them off.

Conclusions

The above analysis provides several insights that may be useful to Capital Bikeshare and other systems for assessing the performance of individual stations and the system overall. First, appropriate measures of imbalance can lead to improved identification of remedies for the problem.

Measuring imbalance using raw counts of outages and trips can obfuscate important trends and insights. Our analysis introduces the effectiveness of using load and service efficiency measures to evaluate station imbalance. We found a clear trend: as the load on a station increases, its service efficiency tends to decrease. Thus taking action to accommodate demand is a necessary step in alleviating imbalance issues.

In our evaluation of station size compared to efficiency it is clear that some smaller and medium sized stations are performing poorly, while the large stations have less severe imbalance issues. It is likely that these larger stations exhibited high raw trip and outage numbers in the past, and in response it is likely Capital Bikeshare increased the number of docks at these stations. Because the medium sized stations have neither the raw trip nor outage numbers of the larger systems, it's possible that imbalance issues at these stations receive less attention. By using more accurate measures, Capital Bikeshare can avoid this potential pitfall, and focus instead on those stations that experience the greatest load, regardless of their size.

From the regression analysis, a further insight for strategic planning is the consistently strong association of road network density with station efficiency. As with walkability, street connectivity is important for the efficient operation of the bikeshare stations in the neighborhood, even as other measures like job density and distance to Metrorail change in significance for the morning and evening commutes. Another spatial variable, difference in elevation, is significant during the highest traffic periods, but not when all traffic is studied, suggesting that hilliness may

be of greater concern during the morning commute than at other times of day. The low elevation of the central business district relative to many of the city's residential areas may also play a role.

This analysis provides a starting point for understanding how to measure imbalance and how environmental and land use factors affect station and system efficiency. Our proposed measures of load and efficiency improve upon raw measures of trips and outages. Assessing other bikeshare systems based on these metrics could help test their overall effectiveness. Additionally, we did not have data regarding the rebalancing operations performed by Capital Bikeshare during the sample data period. Information about rebalancing during the study period would improve our analysis.

Further research will also be needed to more fully describe the interplay between the built environment and demographic characteristics surrounding bikeshare stations and their performance. Future studies could test the factors examined here in greater depth and build upon theory and literature to obviate the use of the stepwise technique

SATELLITE STATIONS: A POSSIBLE SOLUTION

Chronic imbalance might have the effect of driving potential users to other modes of transportation. By adding docking spaces, a station *may* do a better job of handling demand and reducing imbalance.

However, simply adding docks to the current station may not be possible, due to space constraints. In these cases, systems may choose to add another station nearby to serve as a secondary or overflow station. The goal of these "satellite stations" is to add significant capacity to an area, so that the two stations together can better accommodate the demand from bikeshare users and alleviate imbalance issues.

Satellite stations hold particular promise as a possible solution because they strengthen the bikesharing system as a viable transportation option by increasing capacity in high-demand areas. Compared to other potential remedies, like implementing new predictive algorithms, they are a readily available solution. It may also be simpler politically to new stations.

The goal of our satellite station analysis is to examine the following questions: 1) does adding a satellite station alleviate the imbalance that occurred at the initial station; and 2) does adding the satellite station induce latent demand?

Data & Methodology

Identifying Satellite Station Pairs

For this study, we consider a satellite pair to be any pair of stations within 500 feet of each other. At a moderate 3mph pace, 500 feet can be covered in about two minutes. For a CaBi user deciding whether or not to take a trip, this two minute walk represents a very small inconvenience and is unlikely to deter a significant amount of users from taking a particular trip.

Through a GIS analysis of CaBi station locations, we identified 17 station pairs located within 500 feet of each other. In order to study station behavior with and without a satellite station present, we excluded pairs in which the stations were installed within three months of each other, or of the system launch in September 2010. We also excluded triplet stations. This left 10 pairs of stations remaining for analysis.

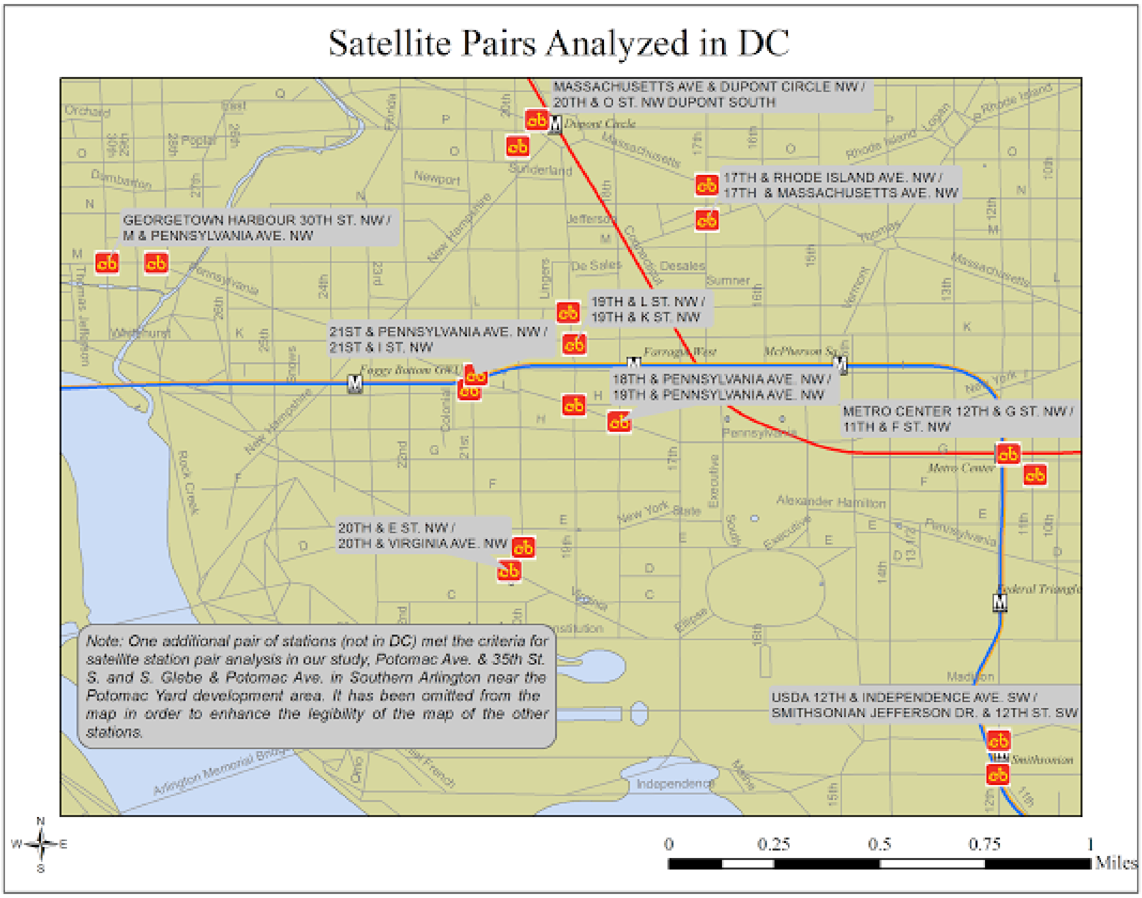

Figure 4.3 Map of Satellite Pairs for Washington, DC Stations

Gathering Station Metrics

To determine the impact a satellite station can have on an initial station, we examined the three months before and the three months after the installation of the satellite station. We compiled arrival and departure information as well as information on the number and the duration of outages (Capital Bikeshare 2013c; *cabitracker.com*). For the three months prior to the installation of the satellite station, we used the data from the initial station only, and for the three months after the installation we combined the data from both the initial station and the satellite station in order to treat the pair as one whole station.

Our analysis only examines weekday trips and weekday outages. Weekdays exhibit more regular traffic characteristics and more severe outage problems. Additionally, we disaggregated the data

by time of day: morning rush (8:00am-11:00), afternoon rush (5:00pm-9:00pm), and non-peak (all other times of the day). The morning and evening rush time periods were selected based on a review of the data to determine peak usage times: these two time periods together account for over half of the total trips and outages occurring at these stations. We used two different methods to analyze the impact of the satellite station. In the first method, we looked at how the satellite pairs changed over the time periods in regards to efficiency and trip load. It is important to note that in the first method an outage at either the initial station or the satellite station in the post time period counts as one outage for the pair collectively. In the second method, we analyzed the percent time that the station and the satellite pair were full or empty. The measure of percent time offers a better alternative to total time full or total time empty, as it gives a more accurate depiction of the likelihood that a user approaching a station will encounter an outage. We call this measure the Bikeshare Level of Service. The important distinction between this method and Method I, is that the Bikeshare Level of Service measure for the initial station and the satellite during the Post time period refers to the times when *both* the initial and satellite station are either full or empty. This was done to more accurately reflect a user's ability to start or end a trip at that location. In their survey response, Fort Worth (TX) Bikesharing reported a similar mindset, placing a lower priority on outages at stations with a nearby station still in service.

Analysis

Full Day

The first step in our analysis was to examine how the initial station performed in the three months prior to the installation of the satellite station (Pre), compared to the performance of the initial station and the satellite station together in the three months after the installation of the satellite station (Post).

In looking at broad performance measures we find that 8 of the 10 pairs saw an overall increase in trips after the satellite station was installed. Potomac Ave. & 35th St. S/S.Glebe & Potomac Ave. was the only pair for which trips as a whole decreased between the Pre and Post periods, and 21st & Eye/21st & Pennsylvania Ave. NW had another station installed between this pair and the nearest Metrorail station, which likely affected traffic. Additionally, these same 8 station pairs experienced a greater increase in trips than the system did as a whole over the same time periods. This suggests that there was latent demand at these locations. By calculating the percent change in our load measure (trips/docks), we see that while 8 of the 10 station pairs experienced total increases in trips, only two stations experienced increased loads (USDA 12th & Independence Ave. SW/Smithsonian Jefferson Dr. & 12th St. SW).

Table 4.7

Change in Imbalance Measures between Pre and Post Satellite Station Installation

	%ΔTrips	%ΔOutages	Demand (%ΔTrips/Dock)	Service Efficiency (%ΔTrips/Outage)
USDA 12th & Independence Ave. SW/ Smithsonian Jefferson Dr. & 12th St. SW	**106.7%**	143.0%	27.2%	-14.9%
Massachusetts Ave & Dupont Circle NW/ 20th & O St. NW Dupont South	**66.7%**	103.0%	15.4%	-17.9%
17th & Rhode Island Ave. NW/ 17th & Massachusetts Ave. NW	**65.6%**	281.4%	-8.0%	-56.6%
19th & L St. NW/ 19th & K St. NW	**53.6%**	17.5%	-42.4%	**30.7%**
20th & E St. NW/ 20th & Virginia Ave. NW	**51.3%**	23.8%	-24.3%	**22.2%**
Georgetown Harbour 30th St. NW/ M & Pennsylvania Ave. NW	**41.5%**	-29.7%	-29.2%	**101.4%**
Metro Center 12th & G St. NW/ 11th & F St. NW	**38.5%**	63.2%	-6.7%	-15.1%
18th & Pennsylvania Ave. NW/ 19th & Pennsylvania Ave. NW	**25.6%**	-4.2%	-37.2%	**31.1%**
21st & Pennsylvania Ave. NW/ 21st & I St. NW	-2.5%	2.0%	-37.9%	-4.3%
Potomac Ave. & 35th St. S./ S. Glebe & Potomac Ave.	-36.2%	-48.6%	-68.1%	**24.1%**

Three station pairs saw a decrease in the total number of outages, and only two of those three stations also experienced an increase in trips (18th & Pennsylvania Ave. NW/19th & Pennsylvania Ave. NW, Georgetown Harbour 30th St. NW/M & Pennsylvania Ave. NW). However, our efficiency measure suggests a different result (Table 4.7). We see that 5 of the 10 station pairs were able to handle more trips before experiencing an outage after the installation of the second station (Potomac Ave. & 35th St. S/S.Glebe & Potomac Ave., 19th & L St. NW/19th and K St. NW, 18th & Pennsylvania Ave. NW/19th & Pennsylvania Ave. NW, Georgetown Harbour 30th St. NW/M & Pennsylvania Ave. NW, 20th & E St. NW/20th & Virginia Ave. NW).

The reason why only half of the stations saw an increase in efficiency may relate to the change in load for all of the satellite pairs. For the five pairs that experienced an increase in efficiency, they all experienced a substantial decrease in load, ranging from -68.1% to -24.3%. This is reasonable, as we expect from the earlier analysis that a decrease in load should lead to an increase in efficiency. Thus for the two satellite pairs that experienced an increase in load, a resulting decrease in efficiency was a likely outcome. Also, two of the satellite pairs experienced relatively modest decreases in load – an 8% decrease for 17th & Rhode Island Ave./17th & Massachusetts Ave., and a 6.7% decrease for Metro Center 12th & G St. NW/11th & F St. NW – that was unlikely to result in an increase of efficiency. The one clear outlier is 21st & Eye St. NW & 21st & Pennsylvania Ave. NW. This pair experienced a substantial decrease in load (37.9%), but also experienced a decrease in efficiency. This is likely related to the installation of another station nearby, at Eye and 22nd St., between this pair and the Foggy Bottom Metrorail station, causing a change in usage patterns unlike those of the other stations.

Breaking this metric down further into arrivals and departures (Table 4.8), we see that eight of the ten station pairs handled more arrivals before becoming full, and five of the ten handled more departures before becoming empty. This difference suggests different factors are at play during periods of heavy arrivals and heavy departures. Each of these satellite pairs experienced an increase in the number of docks, making it able to handle more arrivals before filling up. On the other hand, how quickly a station becomes empty is more dependent on the number of bikes available at the beginning of the rush period, which may be significantly less than the number of docks. While adding more docks means space for more bikes, it does not necessarily mean that stations will actually have more bikes when needed. More information about the rebalancing operations performed by Capital Bikeshare could help explain this finding.

Table 4.8

Percent difference of full and empty bikeshare station pairs.

	%ΔFull	%ΔArv/Full	%ΔEmpty	%ΔDep/Empty
Georgetown Harbour 30th St. NW/ M & Pennsylvania Ave. NW	-28.0%	86.0%	-33.3%	130.2%
18th & Pennsylvania Ave. NW/ 19th & Pennsylvania Ave. NW	20.2%	7.1%	-24.9%	63.5%
19th & L St. NW/ 19th & K St. NW	15.9%	36.5%	19.3%	25.1%
Potomac Ave. & 35th St. S./ S. Glebe & Potomac Ave.	-42.4%	17.3%	-81.8%	225.2%
20th & E St. NW/ 20th & Virginia Ave. NW	4.2%	44.8%	53.1%	-0.9%
21st & Pennsylvania Ave. NW/ 21st & I St. NW	4.3%	-9.1%	0.0%	0.4%
USDA 12th & Independence Ave. SW/ Smithsonian Jefferson Dr. & 12th St. SW	11.1%	79.8%	414.3%	-58.4%
Metro Center 12th & G St. NW/ 11th & F St. NW	41.3%	-2.9%	95.9%	-28.6%
Massachusetts Ave & Dupont Circle NW/ 20th & O St. NW Dupont South	36.3%	19.8%	294.7%	-56.8%
17th & Rhode Island Ave. NW/ 17th & Massachusetts Ave. NW	9.6%	46.2%	548.1%	-73.5%

The results for Method II (Table 4.8) provide more evidence that satellite pairing is an effective strategy to address station imbalance. For this analysis we compare the Bikeshare Level of Service (percent time of outages) for the Pre and Post periods. The results indicate that for each pair there was a reduction in the percentage of time the satellite and the initial station were both full or empty compared to just the initial station in the Pre time period.

Table 4.9

Percentage of time station pairs were out of service.

	%Empty-Pre	%Empty-Post	%Full-Pre	%Full-Post
19th & L St. NW/ 19th & K St. NW	22.6%	6.1%	8.9%	2.5%
18th & Pennsylvania Ave. NW/ 19th & Pennsylvania Ave. NW	14.3%	2.9%	6.2%	2.6%
21st & Pennsylvania Ave. NW/ 21st & I St. NW	10.3%	3.1%	4.8%	1.4%
Metro Center 12th & G St. NW/ 11th & F St. NW	6.1%	1.1%	2.0%	0.7%
17th & Rhode Island Ave. NW/ 17th & Massachusetts Ave. NW	4.8%	2.2%	2.5%	0.0%
20th & E St. NW/ 20th & Virginia Ave. NW	4.4%	1.1%	5.2%	1.0%
Massachusetts Ave & Dupont Circle NW/ 20th & O St. NW Dupont South	2.1%	0.3%	2.9%	0.2%
Georgetown Harbour 30th St. NW/ M & Pennsylvania Ave. NW	1.7%	0.0%	2.3%	0.0%
USDA 12th & Independence Ave. SW/ Smithsonian Jefferson Dr. & 12th St. SW	1.6%	1.1%	1.2%	0.1%
Potomac Ave. & 35th St. S./ S. Glebe & Potomac Ave	0.3%	0.0%	4.5%	0.0%

Morning Rush & Afternoon Rush

Repeating this exercise for the morning rush time period (8:00am-11:00am), we find similar results. Nine of the ten stations saw an overall increase in morning trips, with the exception being Potomac Ave. & 35th St. S/S.Glebe & Potomac Ave. Only two stations saw a percent drop in outages that also experienced a percent increase in trips, 21st & Pennsylvania Ave. NW/21st & I St. NW and Georgetown Harbor 30th St. NW/M & Pennsylvania Ave. NW. Eight of the ten stations became more efficient at handling trips per outage. Further, when comparing the percent duration that both the initial and satellite stations were both full or empty to the Pre time period, all station pairs experienced an improvement.

In the afternoon rush (5:00pm-9:00pm), the results show a similar pattern to the overall results. Again, eight of the ten pairs experienced an increase in trips, with Potomac Ave. & 35th St. S/S.Glebe & Potomac Ave. and 21st & Pennsylvania Ave. NW/21st & Eye St. NW as the outliers. Three stations saw substantial increases in trips. Also, five of the ten stations had increased efficiency in handling trips per outage. Most importantly, every station once again experienced a reduction in the percentage of time that both the initial and satellite stations were full or empty.

Satellite Station Conclusions

Our analysis suggests that satellite stations may effectively address station imbalance. In Method I five of the ten satellite pairs saw an increase in service efficiency. The increased station capacity at these locations allowed many more trips to be handled, while most were able to keep outages from increasing at the same pace. We find that it is important to consider the number of new docks added to the satellite pair. Four of the five stations that experienced decreased efficiency either experienced an increase in load, or only a minor decrease in load that did not result in an increase in service efficiency. Method II suggests that even this second set of pairs remained functional for a greater portion of time. Together our findings suggest that adding even more docks to the second set of station pairs may help improve service efficiency.

Method II illustrates that when evaluating these satellite pairs as one entity, we find evidence that satellite stations can alleviate imbalance. All of the satellite pairs saw an improved Bikeshare Level of Service measure, suggesting that users in those areas were more likely to be able to

make a trip when they wanted, even as most of the station pairs handled more trips overall. The number of trips for most pairs rose faster than for the system as a whole, suggesting that satellite stations provided service for latent demand that could not be served by the original station alone. This suggests that satellite stations may be an effective tool for addressing imbalance, especially in areas with very high demand.

This analysis could not incorporate the way that rebalancing efforts undertaken by Capital Bikeshare impacted service at these stations. This information would provide important context for future analyses.

This analysis also does not examine the conditions necessary for two stations to behave as a satellite pair. We selected the 500 foot buffer used in this analysis as a conservative estimate, to ensure that the stations acted as pairs. For simplicity, we also did not investigate larger groups of stations, though this may be necessary for developing a complete understanding of satellite station behavior. Further analyses of satellite station behavior may make it possible to determine how distance, nearby stations, or other factors relevant to station performance such as street network connectivity, may impact the interactions among stations. Such an understanding would help to inform strategic planning decisions and allow for more efficient deployment of resources.

CAPITAL BIKESHARE ANALYSIS CONCLUSIONS

The results of this study provide a number of useful potential directions, tactics, and metrics for analyzing and addressing station imbalance. Capital Bikeshare and other systems may use these tools to improve their long-term goals and strategic plans, and guide their rebalancing operations. We hope this research enables bikeshare systems to better understand the causes and locations of imbalance, so that they can implement effective solutions.

Operations

The survey of bikeshare systems revealed a number of different operational strategies that staff use to rebalance their systems. While smaller systems rely on the expertise of their rebalancing staff and get by with ad-hoc dispatching, the survey shows that larger systems with more severe balancing issues adopt a more systematic approach. This includes rebalancing staff dividing up

the coverage area into coverage zones, following preplanned routes, and “resetting” high-demand stations to best handle the heavy commute traffic. It also involves the use of more sophisticated monitoring and dispatch tools, allowing staff to respond to problems more quickly. While our analyses of Capital Bikeshare data did not address operational rebalancing explicitly, bikeshare staff may find several of our metrics useful for framing the balancing problem and anticipating areas that need attention.

Performance metrics

Our analysis shows that the performance of bikeshare system depends a great deal on the metrics being monitored. The service efficiency measure (trips per outage) provides a good indicator of performance, allowing the bikeshare system to track the number of users it can serve successfully before experiencing an outage. This may help a system to assess the appropriate deployment of resources to cover its usage. The Bikeshare Level of Service metric reflects the chance that an individual user approaching a station may expect to encounter an outage. Users who frequently experience outages may decide they cannot rely on bikesharing for their trips and opt for another mode of transport. From a planning and resource management perspective, demand metrics like trips per dock can help to assess whether a station is overburdened. Not only may this indicate a higher likelihood of imbalance and station outages, but it represents heavier wear and tear on the dock equipment, which is likely to increase maintenance demands and decrease service life. With further research it may be possible to calibrate these metrics, allowing for real-time monitoring to determine when a station is experiencing heavier demand than it will be able to sustain, and for rebalancing staff to respond before an outage occurs.

Strategic planning

The analyses above contain a number of insights for those involved in a bikeshare system’s strategic plan. Planners should take into consideration system growth, by periodically reevaluating how well existing stations are keeping up with demand. The load and service efficiency metrics can serve as a guide for making these determinations.

The widespread nature of balancing problems indicates that this phenomenon should be taken seriously by operators of current systems, and planned for by the designers of future systems. Numerous environmental and demographic factors affect station outages, especially during

commuting hours. Accounting for variables such as topography, street network connectivity and resident demographics can help to anticipate usage levels when planning out a system or siting new stations. Additionally, in cases where the commuting pattern is particularly pronounced and there are areas of very high demand - as at the mainline rail stations in London - system planners may want to consider using local depots to handle the heavy traffic.

Finally, we found evidence to suggest satellite stations may be a useful tool to address station imbalance. By strategically adding additional capacity in key areas, a bikeshare system can greatly improve the user experience by handling more trips in a small area before suffering an outage. While at first it may seem counterproductive to put two stations so close together, in high-demand locations satellite stations can be effective at handling the existing traffic levels, as well as serving latent demand. We find our Bikeshare Level of Service measure improves upon using the raw total number of outages, and suggests that choosing the right measures of imbalance can impact the proper evaluation of station imbalance.

5 APPENDICES

APPENDIX A. CABI USER INTERCEPT SURVEY

1. **What is your destination? (Select all that apply.)**
   _ My own residence
   _ Residence of family or friend
   _ Short-term residence (i.e. hotel)
   _ Place of employment
   _ Retail store
   _ Neighborhood service (i.e. bank, salon, dry cleaners)
   _ Eating or drinking establishment
   _ Arts, entertainment, or recreation venue (i.e. park, museum, concert venue)
   _ Other________________
2. **How often do you travel to (neighborhood name)?**
   _ It's my first time
   _ Daily
   _ Weekly
   _ Monthly
   _ Other frequency:___________________
3. **Do you plan to return to (neighborhood name) on a daily, weekly, or monthly basis?**
   _ Daily
   _ Weekly
   _ Monthly
   _ Other frequency: __________________
   _ I don't know when I'll return.
4. **How long was your CaBi ride to this station (in minutes)? ____________________**
5. **Why did you travel to (neighborhood name) using CaBi? (Select all that apply.)**
   _ It's too far to walk
   _ Bicycling is faster
   _ There is no bus or Metro/subway option
   _ Parking is limited and/or too expense

_ There is too much traffic in (*neighborhood name*)

_ I wanted the exercise

_ I don't have a car

_ My friends wanted to bike

_ I wanted to save transportation costs

_ It's fun

_ Other____________

6. Which other transportation forms did you take in combination with this CaBi ride to travel to (neighborhood name)? (<u>Select all that apply</u>.)

_ My own automobile

_ Car-share vehicle (ZipCar, Car2Go)

_ Bus

_ Subway (Metro)

_ Commuter rail (VRE, MARC)

_ Taxi

_ My own bicycle

_ A different, separate CaBi ride

_ Other_________________

_ I didn't use any other form of transportation

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7. If a CaBi station was not located in (neighborhood name), would you have traveled to (neighborhood name)?

_ Yes (*Please next answer Question 9 <u>only</u>*.)

_ No (*Please next answer Question 8 <u>only</u>*.)

_ I don't know

8. What would you have done instead of traveling to this neighborhood?

_ Traveled to another neighborhood (e.g. Dupont Circle, Columbia Heights)

_ Stayed home/would not have made a trip

_

9. Which other transportation mode would you have used to travel here? (<u>Select all that apply</u>.)

_ An automobile

_ Bus

_ Subway (Metrorail)

_ Commuter rail (VRE or MARC)

_ Taxi

_ Walking

_ My own bicycle

_ Other ___________

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10. Do you plan to spend money in (neighborhood name) (other than transportation costs)?

_ Yes

_ No

_ I don't know

<u>If you selected Yes</u>, please complete the remaining questions in this section.

<u>If you selected No</u>, please skip to the Respondent Information section.

11. What is the approximate amount you plan to spend?

_ Less than $10

_ $10-24

_ $25-49

_ $50-74

_ $75-99

_ $100 or above

12. Within which walking distance from this CaBi station will that money be spent?

_ Two blocks

_ Four blocks

_ Eight blocks

_ I don't know

13. Would you have spent money (this afternoon/evening) regardless of your trip to (neighborhood name)?

_ Yes

_ No

_ I don’t know

14. Will taking CaBi to (neighborhood name)cause you to spend more, less or the same amount of money than *if you had taken another form of transportation* to (neighborhood name) (excluding the cost of travel)?

_ More

_ Less

_ I don’t know

---

15. What best describes your age?

_ Under 25 years

_ 25 – 34 years

_ 35 – 44 years

_ 45 – 54 years

_ 55 years or above

_ Prefer not to answer

16. Are you male or female?

_ Male

_ Female

_ Prefer not to answer

_

17. What is your household's annual income (in US dollars)?

_ Less than 10,000

_ 10,000 – 14,999

_ 15,000 – 24,999

_ 25,000 – 34,999

_ 35,000 – 49,999

_ 50,000 – 74,999

_ 75,000 – 99,999

_ 100,000 – 124,999

_ 125,000 – 149,999

_ 150,000 – 199,999

_ 200,000 or more

_ Prefer not to answer

18. What is the highest level of education you have completed?

_ Less than high school

_ High school diploma/GED

_ Some college

_ 2-year college degree

_ 4-year college degree

_ Master's degree

_ Doctoral degree

_ Prefer not to answer

19. In which zip code do you live?

_ ____________________

_ Prefer not to answer

_

20. What type of CaBi membership do you have?

_ 24-hour

_ 3-day

_ Daily Key

_ Month

_ Annual

21. In the past month, about how many CaBi trips did you make?

_ No trips

_ 1-2

_ 3-5

_ 6-10

_ 11-15

_ 16-25

_ 26-30

_ More than 30 trips

22. What motivated you to join CaBi? (<u>Select all that apply</u>.)

_ Save money on transportation

_ Get around more easily, faster, shorter time

_ Like to bike and think it's a fun way to travel

_ Take advantage of the exercise opportunity CaBi offers

_ Reduce my carbon footprint

_ Address personal health concerns

_ Have access to another/back-up bicycle

_ Access to another transportation mode

_ Other ________________________

_

23. What type of bicyclist do you consider yourself to be?

_ I will ride regardless of roadway conditions and traffic volume.

_ I'm comfortable sharing the roadway with automobile traffic, but I prefer to do so in a separated bicycle lane.

_ I'm curious about bicycling and like to ride, but I'm often afraid to ride.

_ I'm not at all interested in bicycling

APPENDIX B. BUSINESS PERCEPTION SURVEY

BACKGROUND INFORMATION

1. What best describes your position:
   - Owner, General Manager, or Leading Supervisor
   - Assistant Manager
   - Other (Sales associate, floor staff, waiter, etc.)

2. How long have you worked for/at this establishment?
   - Less than a year
   - 1-2 years
   - 3-5 years
   - More than 5 years

3. How long has this establishment been open at this location?
   - Less than a year
   - 1 - 2 years
   - 3 - 5 years
   - 5 - 10 years
   - 10 - 20 years
   - More than 20 years
   - Don't know

4. How many people work at this establishment?
   - 1-9
   - 10-19
   - 20-29
   - > 30

5. Which age range best describes your typical clientele (select all that apply)?

- Under 25
- 25 – 34
- 35 – 44
- 44 – 54
- 55 and above

6. In your opinion, would you describe your clientele as mostly living:

- Within [*neighborhood name*]
- Outside [*neighborhood name*]
- Balance between those that live outside and within [*neighborhood name*]
- Don't know

7. To the best of your knowledge, over the past 12 months this establishment's overall sales has

- Increased
- No change
- Decreased
- Don't know
- Prefer not to answer

AWARENESS OF BIKESHARE

8. Are you aware of CaBi?

- Yes
- No

If no, read respondent short description of the CaBi program **then skip to question #19.**

"Bikesharing is defined as collection of bicycles that users can rent for a given period of time. The Washington, DC area is home to the CaBi system which is made up of 200 plus stations and 1,800-plus red, three gear bicycles. The system is owned by the governments of the District of

Columbia, Arlington County, city of Alexandria, and Montgomery County and is operated in a public-private partnership with Alta Bicycle Share. To gain access to the bicycles, individuals purchase 1-day, 3-day, month, or year-long memberships."

9. Do any of your employees or colleagues use CaBi to commute to work?

- Yes
- No
- Don't Know

10. Have you ever used CaBi?

- Yes
- No

11. Where is the closest CaBi station?

Open short answer

12. Would you classify your establishment's location relative to the CaBi station(s) as:

- Favorable
- Neutral
- Unfavorable

BIKESHARE AND YOUR ESTABLISHMENT

13. Because of CaBi, daily customer traffic to my establishment has:

- Increased
- Stayed the same
- Decreased
- Don't know

14. Because of CaBi, tourist traffic to my establishment has:

- Increased
- Stayed the same
- Decreased
- Don't know

15. Because of CaBi, customer traffic from those that live outside [*neighborhood name*] has:

- Increased
- Stayed the same
- Decreased
- Don't know

16. Because of CaBi, customer traffic from those that live within [*neighborhood name*] has:

- Increased
- Stayed the same
- Decreased
- Don't know

17. In your opinion, what impact, if any, has CaBi had on sales in your establishment?

- Positive Impact
- Neutral Impact
- Negative Impact
- Don't know

18. In general, what impact, if any, do you think the presence of CaBi stations has on [*neighborhood name*]?

- Positive Impact
- Neutral Impact
- Negative Impact
- Don't know

FUTURE PLANNING AND BIKESHARE

19. Would you be interested in seeing CaBi:

- Install new stations in [*neighborhood name*]
- Remove existing stations in [*neighborhood name*]
- Neither install nor remove stations in [*neighborhood name*]
- Don’t know

20. If someone proposed replacing automobile parking outside your establishment with a CaBi station, what would your reaction be?

- Positive
- Neutral
- Negative

21. If someone proposed replacing sidewalk space outside your establishment with a CaBi station, what would your reaction be?

- Positive
- Neutral
- Negative

22. Would you consider offering special discounts at your store for CaBi members or customers who use CaBi?

- Yes
- No
- I do not make decisions about this establishment’s marketing or promotions

IF YES: Would you be willing to provide your name and business contact information to CaBi (all other survey answers will remain confidential)?

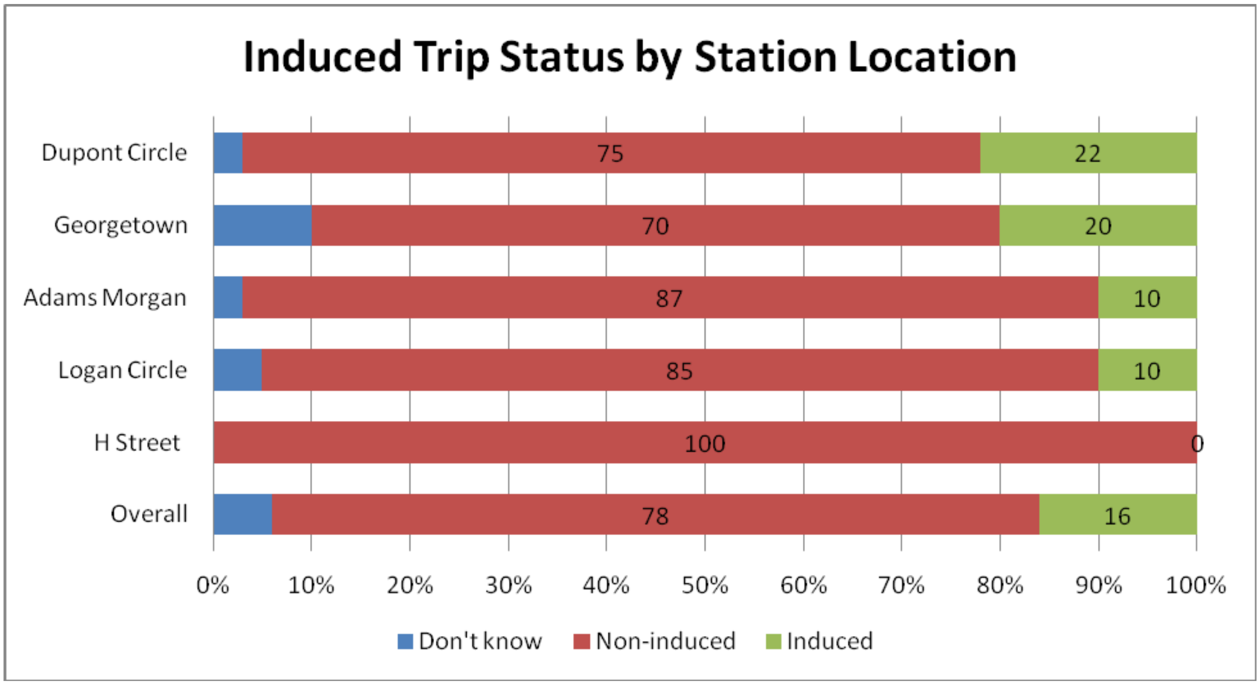
Name:

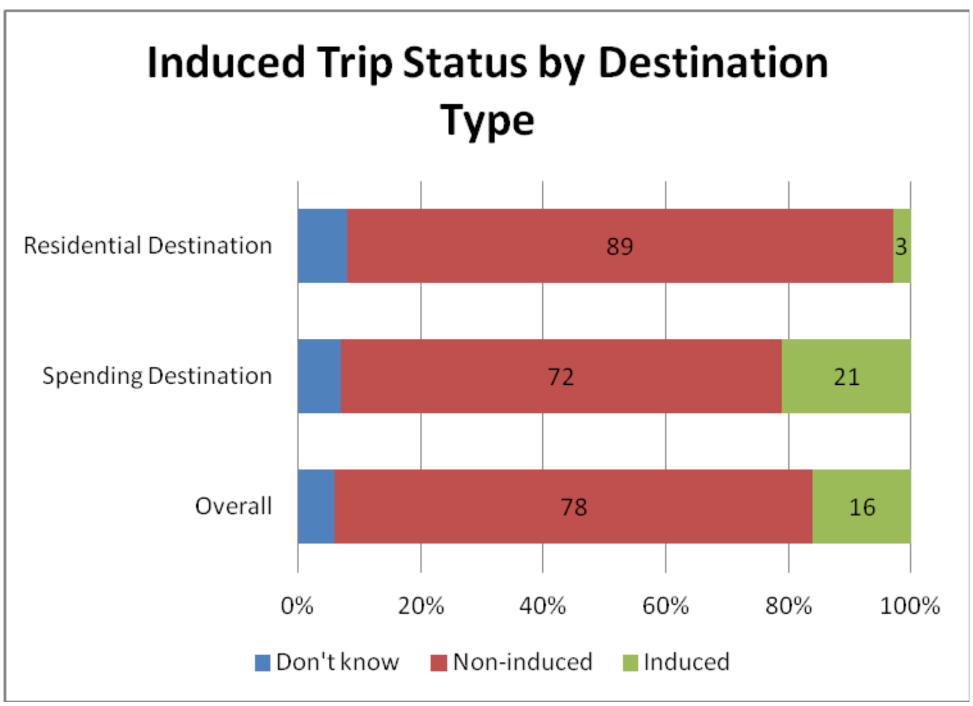
Company:

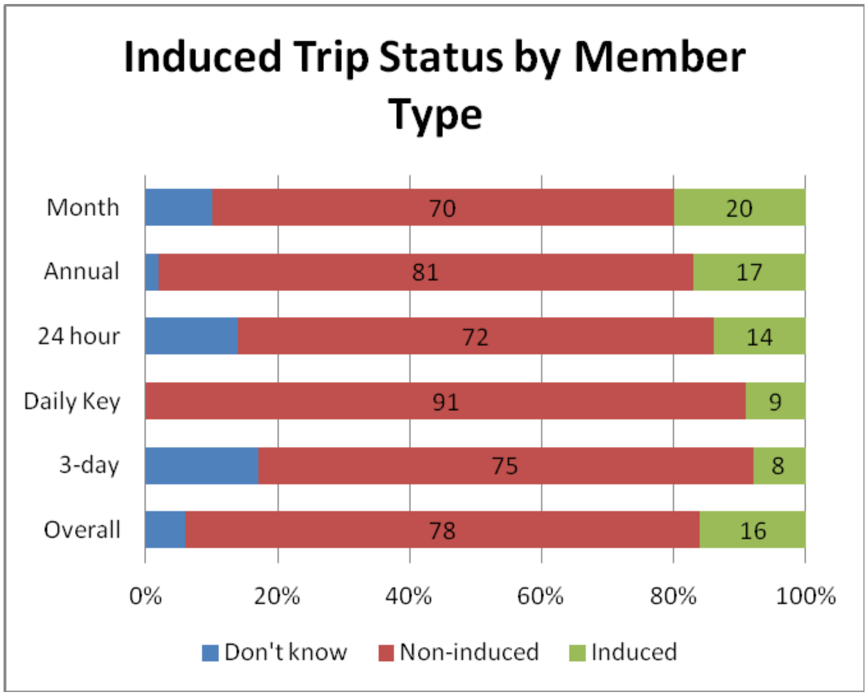
Email:

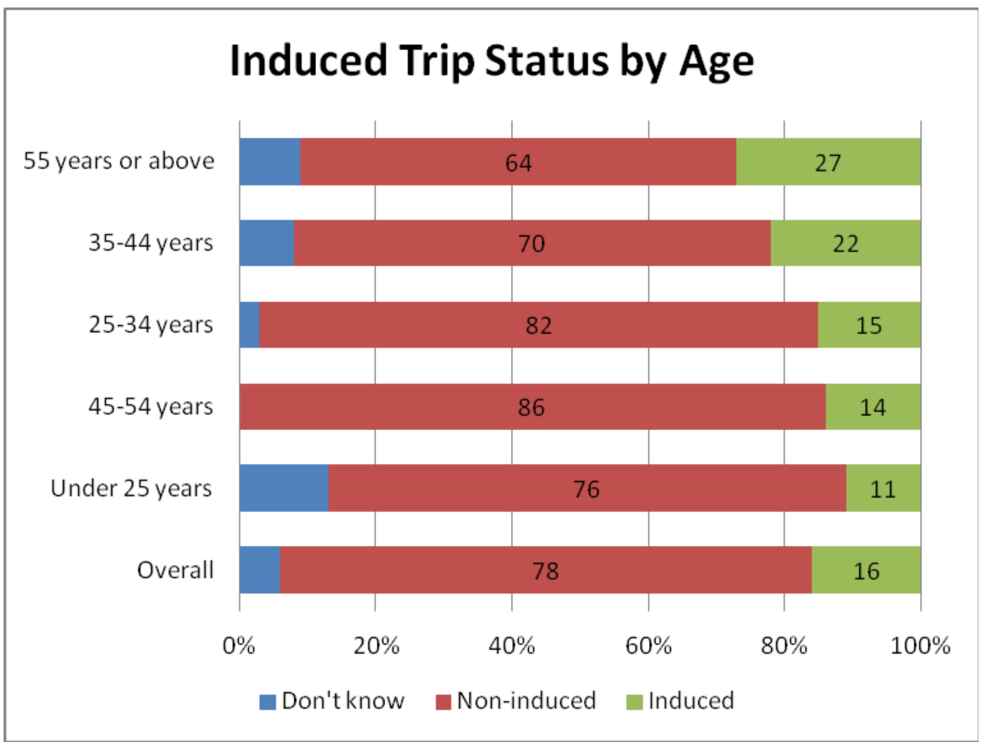
APPENDIX C. KEY VARIABLES.

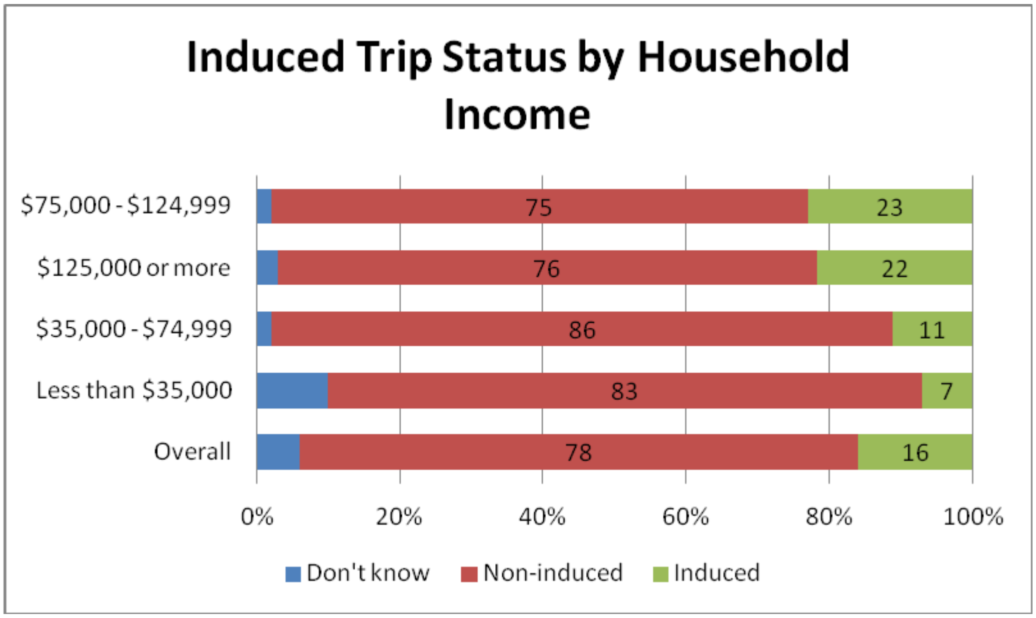
Induced Trips





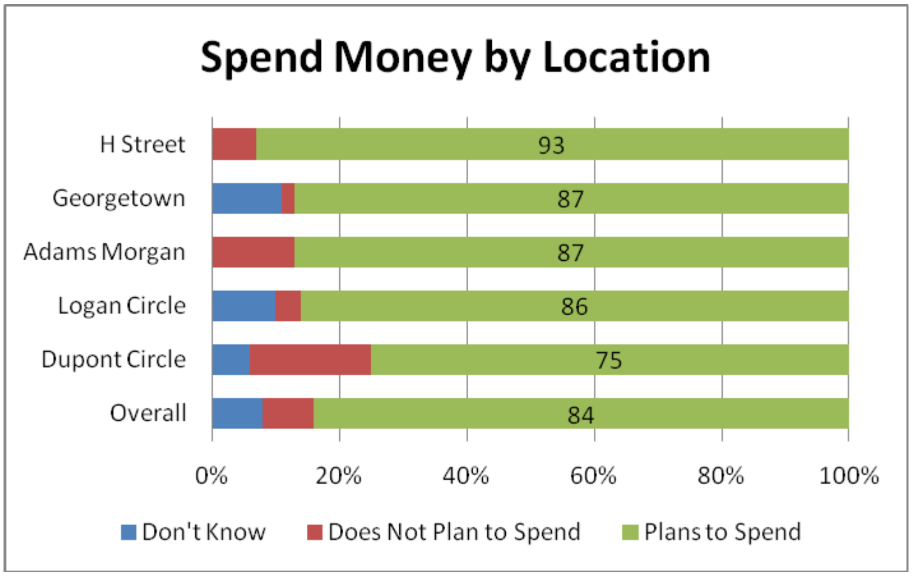

Induced Trip Status by Member Type
Month
Annual
24 hour
Daily Key
3-day
Overall
70
20
81
17
72
14
91
9
75
8
78
16
0%
20%
40%
60%
80%
100%
Don't know
Non-induced
Induced

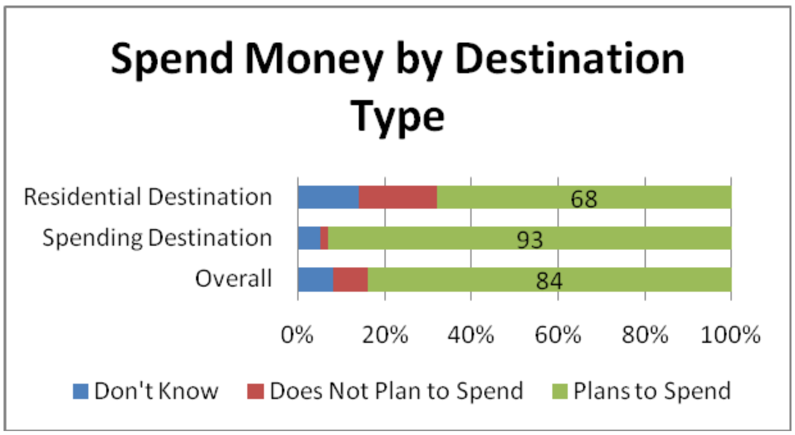

Induced Trip Status by Age
55 years or above
35-44 years
25-34 years
45-54 years
Under 25 years
Overall
64
27
70
22
82
15
86
14
76
11
78
16
0%
20%
40%
60%
80%
100%
Don't know
Non-induced
Induced

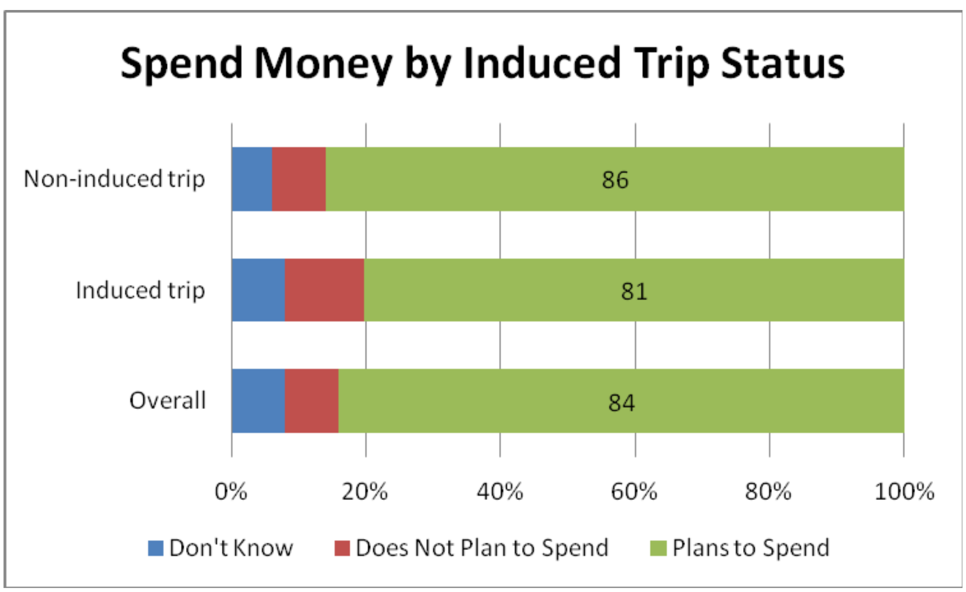


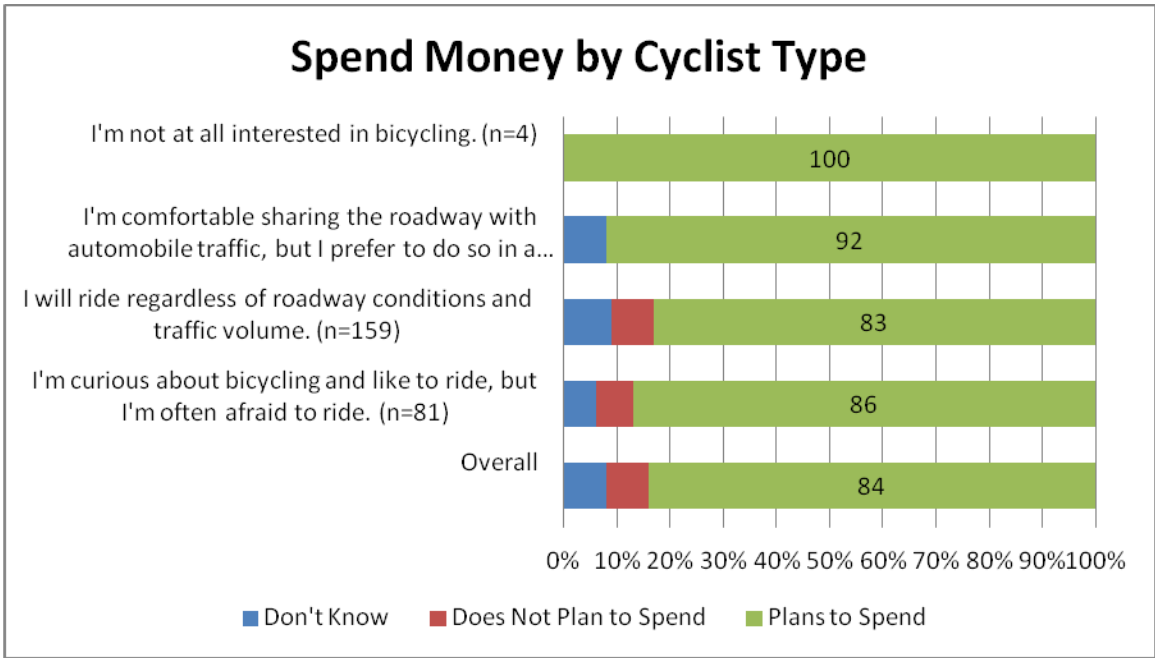
Induced Trip Status by Household Income
$75,000 - $124,999
$125,000 or more
$35,000 - $74,999
Less than $35,000
Overall
75
23
76
22
86
11
83
7
78
16
0%
20%
40%
60%
80%
100%
Don't know
Non-induced
Induced

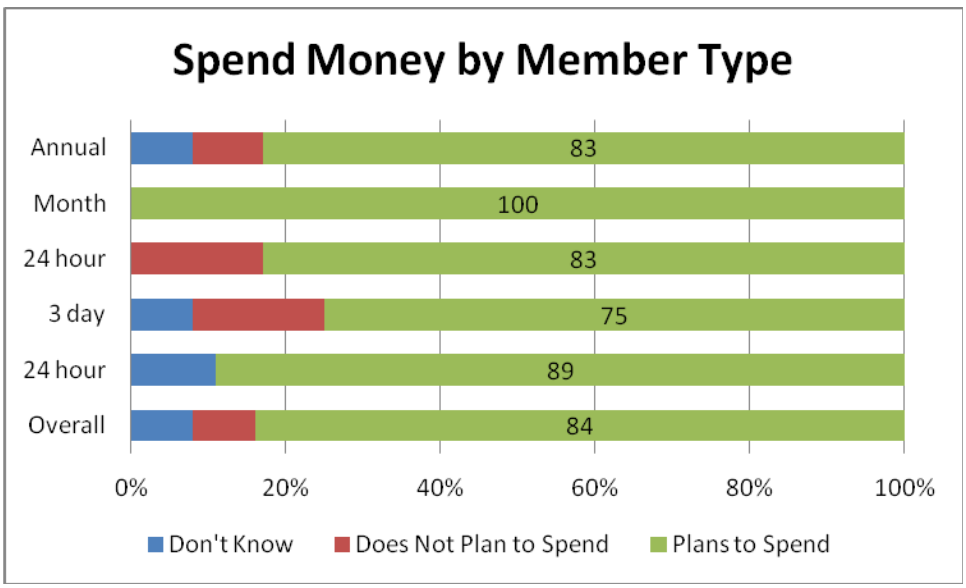
Spend Money

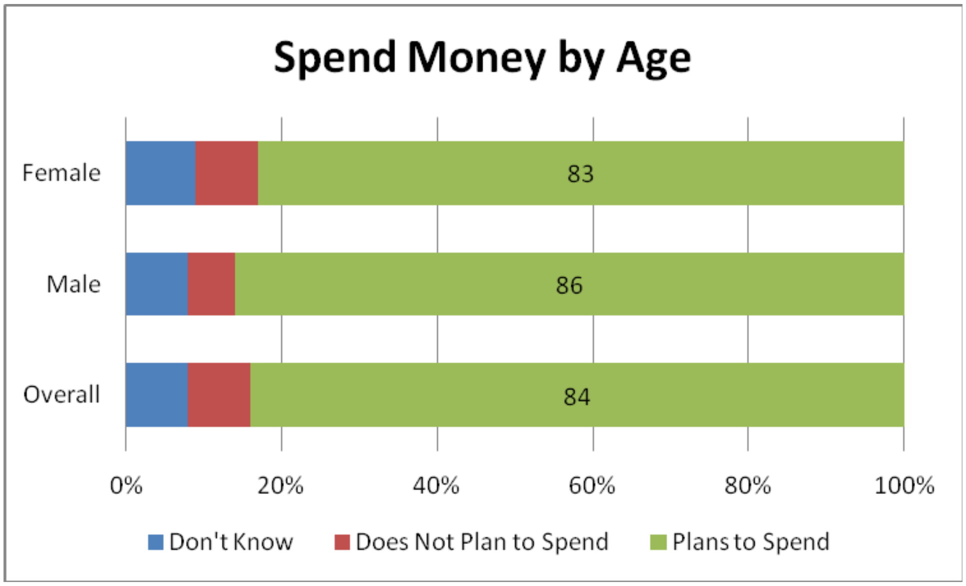

Spend Money by Location
H Street
Georgetown
Adams Morgan
Logan Circle
Dupont Circle
Overall
93
87
87
86
75
84
0%
20%
40%
60%
80%
100%
Don't Know
Does Not Plan to Spend
Plans to Spend

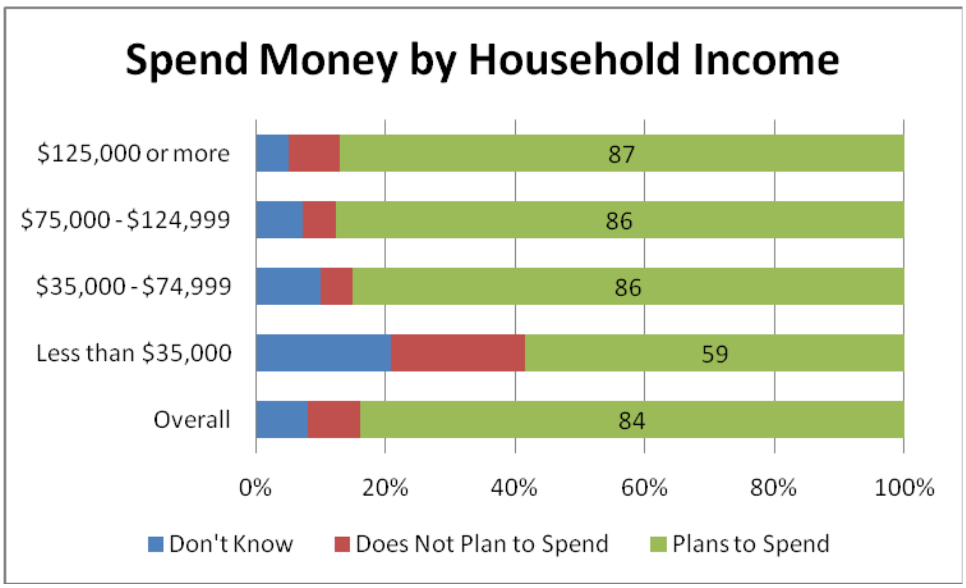

Spend Money by Destination Type
Residential Destination
Spending Destination
Overall
68
93
84
0%
20%
40%
60%
80%
100%
Don't Know
Does Not Plan to Spend
Plans to Spend


Spend Money by Induced Trip Status
Non-induced trip
Induced trip
Overall
86
81
84
0%
20%
40%
60%
80%
100%
Don't Know
Does Not Plan to Spend
Plans to Spend

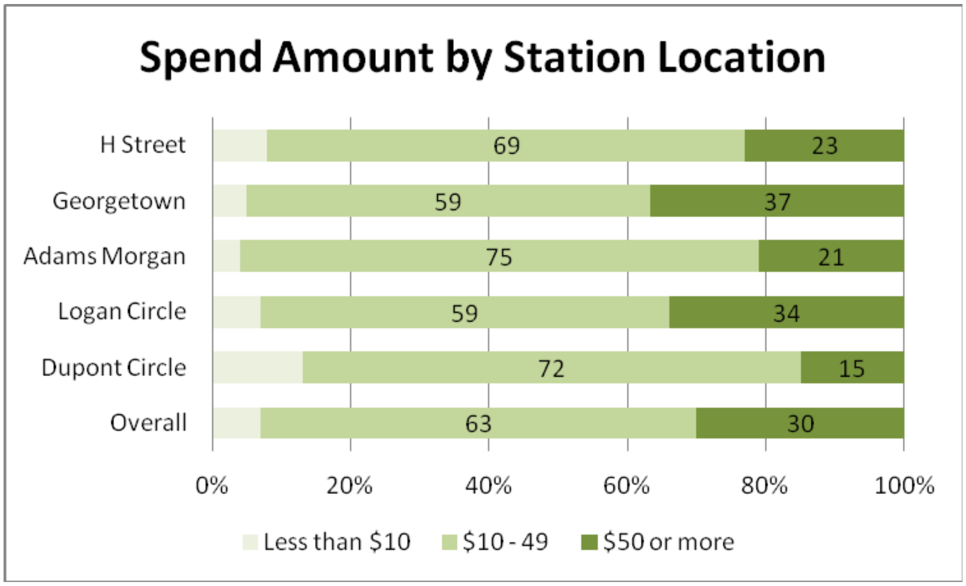

Spend Money by Cyclist Type
I'm not at all interested in bicycling. (n=4)
I'm comfortable sharing the roadway with automobile traffic, but I prefer to do so in a...
I will ride regardless of roadway conditions and traffic volume. (n=159)
I'm curious about bicycling and like to ride, but I'm often afraid to ride. (n=81)
Overall
100
92
83
86
84
0% 10% 20% 30% 40% 50% 60% 70% 80% 90%100%
Don't Know
Does Not Plan to Spend
Plans to Spend

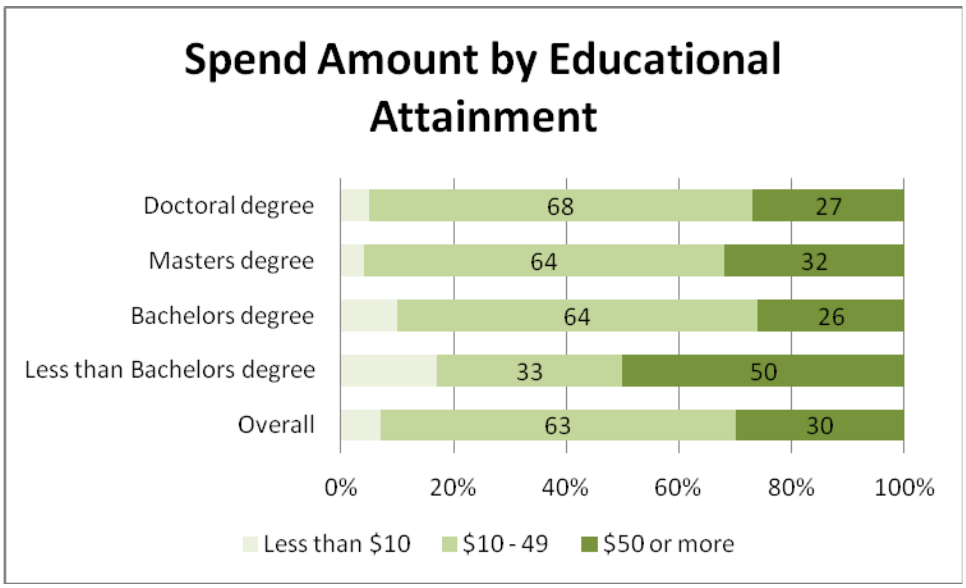

Spend Money by Member Type
Annual
Month
24 hour
3 day
24 hour
Overall
83
100
83
75
89
84
0% 20% 40% 60% 80% 100%
Don't Know
Does Not Plan to Spend
Plans to Spend


Spend Money by Age
Female
Male
Overall
83
86
84
0%
20%
40%
60%
80%
100%
Don't Know
Does Not Plan to Spend
Plans to Spend


Spend Money by Household Income
$125,000 or more
$75,000 - $124,999
$35,000 - $74,999
Less than $35,000
Overall
87
86
86
59
84
0%
20%
40%
60%
80%
100%
Don't Know
Does Not Plan to Spend
Plans to Spend

Spend Amount





APPENDIX D. BIKESHARING SYSTEMS SURVEY

Table 5.1. Primary Systems Classification

Primary Systems					
Name	*Location*	*Bikes*	*Population*	*Area (sq. mi)*	*Density*
Vélib	Paris, France	20000	2,211,000	40.7	54,324
Barclays Cycle Hire*	London, UK	9200	8,174,000	607	13,466
Bicing*	Barcelona, Spain	6000	1,621,000	39.34	41,205
Citi Bike	New York, NY	6000	8,337,000	468	17,814
Bixi Montreal	Montreal, Canada	5120	1,620,000	141	11,489
Vélo'v	Lyon, France	4000	475,946	18.51	25,713
Ecobici	Mexico City, Mexico	4000	8,851,000	573	15,447
Divvy*	Chicago, IL	4000	2,715,000	227.2	11,950
Nextbike	Various German cities	3000	687,775	N/A	N/A
ValenbiSi!	Valencia, Spain	2750	809,000	51.99	15,561
Villo!	Brussels, Belgium	2500	1,119,000	62.2	17,990
Sevici	Sevilla, Spain	2500	702,355	54	13,007
Capital Bikeshare*	**Washington, D.C. Metro**	**2500**	**632,323**	**61.4**	**10,298**
VéloToulouse	Toulouse, France	2400	439,553	45.7	9,618
CityCycle	Brisbane, Australia	2000	2,043,000	527.8	3,871
Velo	Antwerp, Belgium	1800	480,721	78.96	6,088
Vélo Bleu	Nice, France	1750	344,875	27.77	12,419
Tel-O-Fun	Tel Aviv, Israel	1630	404,037	20	20,202
Nice Ride*	Minneapolis & St. Paul, MN	1550	683,650	110.38	6,194
VCUB	Bordeaux, France	1545	235,891	19.06	12,376
Hubway*	Boston, MA	1065	636,479	48	13,260
Decobike*	Miami Beach, Florida	1000	413,892	35.68	11,600
Bixi Toronto	Toronto, Canada	1000	2,503,000	240	10,429
MVGmeinRAD*	Mainz, Germany	1000	200,957	37.74	5,325
Bizi	Zaragoza, Spain	1000	679,624	410.29	1,656
Median Stats		***2,500***	***687,775***	***58***	***12,398***

Table 5.1 Notes:

* Denotes systems that returned completed questionnaires. Minneapolis & St. Paul populations combined for this figure.
Fort Lauderdale's population used to represent Broward county.

Ottawa & Gatineau populations are combined for this figure.

Table 5.2. Secondary Systems Classification

Secondary Systems					
Name	*Location*	*Bikes*	*Population*	*Area (sq. mi)*	*Density*
Bicloo	Nantes, France	875	283,288	25.17	11,255
Le Vélo	Marseille, France	700	851,420	93	9,155
Bay Area Bike Share	San Francisco Bay Area	700	825,863	46.87	17,620
Denver B-Cycle	Denver, CO	600	634,265	153.3	4,137
Melbourne Bike Share	Melbourne, Australia	600	4,077,000	3400	4,059
San Antonio B-Cycle*	San Antonio, TX	600	1,383,000	460.93	3,000
Dublinbikes	Dublin, Ireland	550	527,612	45.5	11,596
UCycle	Nottingham, UK	460	305,700	46.5	6,574
Hire-a-Bike	Blackpool, UK	400	142,100	13.46	10,557
DB Rent GmbH	Various, incl. Hamburg	400	1,813,587	292	6,211
Bicipalma	Palma, Spain	336	407,648	80.55	5,061
Bike Rio	Rio de Janeiro, Brazil	300	6,230,000	456.5	13,647
CoGo*	Columbus, OH	300	809,798	217.17	3,729
Fort Worth B-Cycle*	Fort Worth, TX	300	777,992	342.2	2,274
Madison B-Cycle*	Madison, WI	300	240,323	76.79	3,130
Bike Chattanooga*	Chattanooga, TN	300	171,279	135.2	1,267
Luzern Nextbike	Luzern, Switzerland	280	76,419	6.1	12,528
Broward B-Cycle	Broward County, FL	275	170,747	34.7	4,921
Girocleta	Girona, Spain	260	97,198	15.11	6,433
StadtRAD Hamburg	Hamburg, Germany	250	1,813,587	292	6,211
Capital Bixi	Ottawa -Gatineau	250	1,125,516	326.22	3,450
Velopop’	Avignon, France	200	94,787	25.01	3,790
Charlotte B-Cycle	Charlotte, NC	200	775,202	297.7	2,604
bicielx*	Elche, Spain	200	230,587	125.9	1,832
EnCicla*	Medellin, Colombia	150	2,184,000	147	14,857
b’bici	Pamplona, Spain	101	197,604	9.093	21,731
PubliBike	Bern, Switzerland	54	123,154	19.92	6,182
Median Stats		***300***	***527,612***	***93***	***6,182***

Table 5.3. Primary System Survey Respondents.

Primary Systems					
Name	*System*	*Contact*	*Lang.*	*Date*	*Response*
Vélib	Cyclocity	Online form; Twitter	English French		
Barclays Cycle Hire*	Bixi/Serco	Online form; Email	English	27-Nov	survey.vt.edu
Citi Bike	Bixi/Alta	Email; Twitter	English		
Bicing*	Clear Channel	Email	English Spanish	18-Nov	survey.vt.edu
Bixi Montreal	Bixi	Email; Phone	English; French		
Vélo'v	Cyclocity	Online form	English French		
Ecobici	Clear Channel	Online form	English Spanish		
DB Rent GmbH	Next Bike	Email	German; English		
Divvy*	Bixi/Alta	Email	English		survey.vt.edu
ValenbiSi!	Cyclocity	Email	English; Spanish		
Villo!	Cyclocity	Email	French; English		
Sevici	Cyclocity	Online form	English Spanish		
Capital Bikeshare*	**Bixi/Alta**	**Email**	**English**	**18-Nov**	**survey.vt.edu**
VéloToulouse	Cyclocity	Online form	English French		
CityCycle	Cyclocity	Email	English		
Velo	Clear Channel	Email	French; English		
Vélo Bleu	OYBike	Online form	English French		
Tel-O-Fun	N/A	Online form	English		
Nice Ride*	Bixi/Alta	Email	English		email
VCUB	Keolis	Email	English French		
Hubway*	Bixi/Alta	Email	English		survey.vt.edu
MVGmeinRAD*	MVGmeinRAD	Email	German; English		email
Decobike*	Sandvault	Email	English		survey.vt.edu
Bizi	Clear Channel	Email	Spanish; English		

Table 5.4. Secondary System Survey Respondents.

Secondary Systems					
Name	*System*	*Contact*	*Lang.*	*Date*	*Response*
Bicloo	Cyclocity	Phone	English; French		
Le Vélo	Le Vélo	Online form	English; French		
San Antonio B-Cycle*	B-Cycle	Email	English		survey.vt.edu
Melbourne Bike Share	Bixi	Email	English		
Denver B-Cycle	B-Cycle	Email	English		
Bay Area Bike Share	Alta	Email	English		
Dublinbikes	N/A	Online form	English		
UCycle	Sustrans & Evans Cycles	Email	English		
Hire-a-Bike	Hourbike	Email	English		
Callabike Stuttgart*	N/A	Email	German; English	7-Nov	survey.vt.edu
Bicipalma	N/A	Email	Spanish; English; German		
Madison B-Cycle*	B-Cycle	Email	English		survey.vt.edu
Fort Worth B-Cycle*	B-Cycle	Email; Phone	English		survey.vt.edu
CoGo*	Alta	Email	English	30-Oct	survey.vt.edu
Bike Rio	Mobilicidade	Online form	English, Spanish		
Bike Chattanooga*	Bixi/Alta	Email	English	7-Nov	survey.vt.edu ; email
Luzern Nextbike	Nextbike	Email	German; French; English		
Broward B-Cycle	B-Cycle	Email	English		
Girocleta	N/A	Email	Spanish; Catalan; English		
StadtRAD Hamburg	Call a Bike Flex	Email	German; English		
Capital Bixi	Bixi	Online form	English		
Velopop’	Smoove	Online form	French; English		
Charlotte B-Cycle	B-Cycle	Online form	English		
bicielx*	N/A	Online form	Spanish; English	21-Nov	survey.vt.edu
EnCicla*	N/A	Email	Spanish; English		survey.vt.edu
b’bici	N/A	Email	Spanish; English		
PubliBike	PubliBike	Email	German; French		

Bikeshare System Questionnaire

Thank you for taking the time to complete this survey for our bikeshare research.

We are graduate students at Virginia Tech looking to collect best practices information from peer bikeshare systems in an effort to optimize operations within our local bikeshare system. Our main interest lies in better understanding the topic of rebalancing. Our research team has identified several questions that we are particularly interested in. At any time, you may elect to leave a question unanswered.

The survey can be completed in this document and emailed to bikeshare@vt.edu. Alternatively, this survey is also available on survey.vt.edu.

Bikeshare Demand

Your responses in this section will provide us with useful information about your system's capacity and demand.

1. How many docking spaces are in your bikeshare program's:

a. largest station ___

b. smallest station ___

c. average station ___

2. What is the average number of rides in your bikeshare system for:

a. a typical weekday? _____

b. a typical weekend? _____

c. Do you use any other numbers that measure volume of usage? Y / N

If so, what are those metrics? ___________________________

3. At what time(s) does peak weekday usage occur?

____ a. Before 09:00

____ b. 09:01-12:00

____ c. 12:01-15:00

____ d. 15:01-18:00

____ e. 18:01-21:00

____ f. After 21:01

System Balancing

The following sections will address the need for rebalancing in your system and the challenges your system faces in this regard. Keep in mind the following terms when answering these questions.

Unbalanced stations are *stations that do not have bikes (or empty dock spaces) where users need them.*

Rebalancing is the process of *moving bikes to stations where users need them; removing bikes to create dock spaces where users need to park.*

4. To what degree is balancing a challenge or an issue for your bikeshare system?

a) Not a challenge

b) Minor challenge

c) Moderate challenge

d) Serious challenge

5. What do you think causes the imbalance in your bikeshare system?

(Select all that apply.)

__ Spatial layout of city

__ Street network

__ Topography

__ Station locations (in terms of user demand or physical surroundings)

__ Lack of station density

__ Demographics

__ System does not have imbalances

__ Other ___________________________

5.1 Please elaborate on how the items identified in question 5 above contribute to the ‘balancing’ problem

6. Does your system undertake efforts to ensure that system is balanced?

___ Yes → If yes, please proceed to question number 7 on the next page.

___ No → If no, please skip to question number 23 on page 7.

7. Do you rebalance stations on a daily schedule? Y / N

What is the rationale behind scheduled rebalancing?

(For example: some systems rebalance their stations each day before the morning commuting hours)

8. What triggers an unscheduled rebalancing?

(For example: weather, special events, unexpected availability)

9. How do you determine if an individual station needs to be rebalanced?

10. What is the strategy for rebalancing bikes? Check all that apply.

__ pre-determined route

__ staff responsible for rebalancing within geographic zones

__ direction from a central dispatcher

__ communication between rebalancers

__ other

If other, please elaborate on your rebalancing strategy.

11. What is the target availability of bikes at stations?

(For example: 1:2 bike:dock ratio system-wide, 60% of docks full, etc.)

12. Other than target availability, are there alternative measures or numbers metrics your bikeshare system uses to assess how balanced the system or stations are?

13. What types of stations need rebalancing?

__ Commuter stations

__ Large stations

__ Small stations

__ Uphill/downhill stations

__ Tourist attraction stations

__ Other ____________________

Resources for Rebalancing

Employees

14. How many full time equivalent (FTE) staff work on rebalancing the system?

15. Do labor contracts constrain working hours (for example, restricted night hours)?

16. Do rebalancers perform other tasks while rebalancing (for example, maintenance or repairs)?

Vehicles

17. Please describe the type of vehicles used to rebalance stations in your bikeshare system. For example, the size of vehicle and amount of bicycles it can transport.

Warehouses

18. a. How many warehouses does your bikeshare system use? ___

b. Where are they located relative to the majority of the stations (for example, distance to stations)?

19. Are there any future plans to consolidate or increase the number of warehouses in the system? Why?

Technology

20. Describe any technology used to assist rebalancers during their shifts. Was this technology created by your bikeshare system? Can the public access the same technology? *(For example: mobile apps, web portals showing bike/dock availability)*

Incentives

21. Has your bikeshare system used incentives to encourage riders to assist in rebalancing?Y / N

If yes, how? Has this incentive program been effective? *(For example: reduced prices for bikeshare users that ride from stations that are typically full to stations that are typically empty, or extra time for uphill rides)*

Peer Systems

22. Please elaborate on any specific lessons you have learned from other bikeshare programs on how to improve service and rebalancing, if any?

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