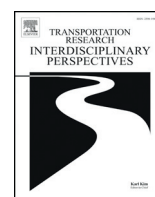




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Toward sustainable travel: An analysis of campus bikeshare use

Sanaz Aliari ^{a,*}, Arefeh Nasri ^b, Mohammad Motaleb Nejad ^a, Ali Haghani ^a

^a Civil and Environmental Engineering, University of Maryland, College Park, United States of America

^b National Center for Smart Growth, University of Maryland, College Park, United States of America

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ABSTRACT

In this study, we use University of Maryland's (UMD) bikeshare ridership data along with historical weather data, elevation, and transit service location data to analyze bikeshare trip patterns and explore the various factors influencing demand for the system across the UMD campus. We analyzed the spatial, temporal, and environmental factors influencing trips within a 19-month period to shed some light on how the bikeshare system is being used across campus and in its surroundings and to determine the most important factors shaping the demand. Results show that, similar to the city-wide bikeshare systems, demand for campus bikeshare is mostly influenced by weather, time of day, day of the week, month of the year, and accessibility to transit and various other destinations. However, unlike the city-wide bikeshare systems, there is not a concentration of trips within peak hours, as trips are scattered throughout the day. This is probably due to the flexible working schedules of bikeshare users on-campus (i.e., students and faculty), as opposed to the users of city-wide systems. Additionally, results indicate a higher on-campus usage of the system within the proximity of the transit hubs with a median trip duration of 6.8 min which supports the complementary relationship between bikeshare system and conventional transit systems.

1. Introduction

Bikeshare programs were introduced several years ago to facilitate and encourage biking as a sustainable mode of transportation and make it as convenient as possible for everyday use. Promoting active travel through bikesharing programs in small- and medium-sized communities such as university campuses has many individual and community-wide benefits. Individuals benefit from bikesharing as they increase their levels of physical activity, reduce their transportation costs, and reduce auto dependency and time spent in traffic. Communities also benefit from these programs as they save fuel and energy, and reduce parking demand, congestion, and environmental emissions (Kelarestaghi et al., 2019). Therefore, many colleges and universities have provided on-campus bikeshare programs for their students, faculty, and staff to get around campus and into the community at large. Similar to city-wide bikeshare programs, these campus-wide systems are increasingly growing and gaining popularity at many university campuses across the country.

University campuses are unique in their mix of population, their transportation and movement patterns throughout the day, and their irregular work schedules. Students are expected to have a different travel pattern from the general population because they usually have partial control and flexibility over their work schedules and commute times, which enables them to adjust departure times to avoid peak hour traffic (Khattak et al., 2011). They are usually younger, unmarried (and/or have no children),

lower-income, and have lower car ownership compared to the general population. Therefore, students tend to be more flexible in their mode choice decisions and more likely to use transit and non-motorized modes on a daily basis (Zhou, 2012). All these factors, plus the pro-active educational milieu of the colleges and universities, make them ideal places to promote sustainable mobility through reshaping society's travel patterns and encouraging active transportation (Balsas, 2003).

The University of Maryland (UMD) used to have a relatively low bicycle mode share compared to many other universities. According to a 2009 survey for the UMD Campus Bicycle Study, only 5% of respondents reported using bikes for commuting (University of Maryland Campus Bicycle Study, 2009). UMD has thus been making planning decisions that promote biking as an active daily commute mode among students and staff, and proposed strategies—such as bike lanes, bicycle parking, and a bikeshare program—which increased the bicycle mode share to 9% and 15% by 2012 and 2019, respectively, according to UMD's transportation officials.

UMD's bikeshare program was launched in May 2016 with 14 stations and 125 bikes; it was expanded to 24 stations, on- and off-campus, with 179 bikes in service as of June 2019. Potential users of the bikeshare program are both students and employees, as well as visitors. The program was implemented in response to reduced parking spaces across campus within the last few years and is expected to also reduce greenhouse emissions and congestion across campus as more students use the bikes to get to and around campus.

The bikeshare trip data can be used to better understand travel patterns among university students and staff and evaluate the system's performance. This study uses the 2009 survey and bikeshare trip data obtained from the

* Corresponding author.

E-mail address: saliyari@umd.edu. (S. Aliari).

system's operating company, to focus on the routine daily journeys made to and from the UMD campus using the bikeshare system. Travel patterns are investigated by analyzing various trip characteristics such as origin/destination locations, time of day/day of the week, length, and frequency, taking into account weather conditions using historical weather data—temperature and precipitation—and topography (i.e., elevation) in both trip directions.

Regardless of the size of the bikeshare system and the city, previous literature suggests that multiple factors should be considered when analyzing a bikeshare system. Those factors include distance from the central business district (CBD) or major employment centers, proximity to various destinations and amenities, presence in higher-density residential areas, and nearby bike infrastructure (Nasri et al., 2018; Buck and Buehler, 2012; Faghih-Imani and Eluru, 2016). However, a bikeshare use and travel patterns are different in large cities vs. small communities and university campuses. Thus, it is important to investigate ridership patterns and factors associated with a university campus setting by tracking station usage throughout the day, stations' trip records and bike turnarounds, spatial distribution of stations, and bikeshare network's spatial connectivity. Accordingly, our analysis examines the following questions:

- How would station location (latitude, longitude, elevation) affect demand?
- How would weather conditions (precipitation, temperature, etc.) affect demand?
- How would the time of day, day of the week, and month of the year affect demand?
- What is the average ride time?
- What is the average trip duration for frequently used stations?
- Do frequently used stations have shorter trips?
- Should stations be added, removed, or relocated? If yes, where are the potential candidate locations?

The results of this study can help UMD's transportation planners better plan and operate UMD campus's bikeshare program and help identify potential locations for system expansions by identifying trip clusters where there are no stations nearby. It is also useful for transportation and urban planners and decision-makers as well as environmental activists and campus planners at UMD and other universities to analyze and measure the impacts of such programs on emission reduction and environmental air quality. Along with universities and colleges, this study would be of interest to other campus environments such as science and research parks and office complexes that are planning to provide bikeshare programs as green transportation mode for employees and visitors.

2. Literature review

Cycling, as an active mode of transportation, has various social, economic, environmental, transportation, and health benefits (Pucher and Buehler, 2012; Rabl and De Nazelle, 2012). It is recognized that promoting biking can make university campuses more attractive and desirable for students and employees, while supporting sustainable transportation goals. Thus, colleges and universities often seek to promote active travel and reduce auto dependency for its various individual and community benefits. In the past, this promotion has included offering various monetary incentives such as carpool incentives (Lue and Colorni, 2009), free bicycle rental programs (Balsas, 2003; Toor and Havlick, 2004; Tang, 2010), and transit ridership encouragement such as reduced fares (Zhou, 2012; Brown et al., 2001) to promote transit ridership and encourage active travel.

Since the emergence of bikeshare programs in cities around the world, colleges and universities also started to consider it as a way to cope with excessive automobile use and dependency, hopefully with a long-lasting impact. Studies have focused on various aspects of bikeshare such as their effect on increasing the level of active transportation and transit ridership, improving health via promotion of physical activity, and other benefits (Nasri et al., 2018; DeMaio, 2009; Younes et al., 2019). These systems are expected to complement transit use and encourage non-motorized travel

by providing fast and easy access to bikes at a network of stations where bikes can be picked up and returned (Faghih-Imani and Eluru, 2016).

However, bikesharing research has focused on large, city systems as opposed to systems in small communities and on university campuses (Audikana et al., 2017). Although bikeshare systems in large and small contexts share some benefits, including promoting active transportation and complementing transit use as a first- and last-mile facilitator, the objectives of implementing these systems in small communities and university campuses are usually different from those in large cities with extensive transit networks. Therefore, different outcomes and benefits are expected, with many issues specific to each context.

For instance, the challenges of implementing and managing bikeshare systems in small communities are considerably different from those in large cities (Audikana et al., 2017). Accessibility, safety, and social equity issues are significant challenges influencing bikeshare demand in large cities (Fishman et al., 2012; Lathia et al., 2012). But for a university campus bikeshare system, they are less significant (Audikana et al., 2017) because the users' socio-demographic characteristics and the system's geographic coverage present considerably lower safety and equity concerns. Similarly, the usage pattern, the ridership and health effects, and effects on the overall transportation system (such as parking demand, traffic congestion, and transit use) are different for the bikeshare systems in large cities vs. small communities and university campuses.

Thus, it is necessary to analyze a bikeshare system specifically within the context of small communities and university campuses to investigate its various impacts on travel behavior and transportation systems more comprehensively and efficiently. The findings could support better operation, planning, and expansion of the systems, especially as more colleges and universities consider their implementation or update their existing systems with improved service and/or dockless programs.

Although various factors influence individual travelers' mode choice in all population groups, not all these factors have the same significance and weight for mode choice decisions within different population groups (Zhou, 2012). Several studies investigated mode choice behavior, especially for active modes, among students and campus communities and suggested that departure time choice flexibility should be more important given the flexible work schedules of students, faculty, and staff (Akar et al., 2012; Zhou, 2014; Abasahl et al., 2018; Whalen et al., 2013; Lundberg and Weber, 2014; Delmelle and Delmelle, 2012; Limanond et al., 2011; Danaf et al., 2014). Most of these studies suggest that factors such as increased travel time and transit and personal car accessibility are the main factors in students' choice of these transportation modes.

While many studies analyzed bicycle use and behavior on university campuses (Kelarestaghi et al., 2019; Balsas, 2003; Wuerzer and Mason, 2015), very few focused specifically on bikeshare as an innovative alternative transportation mode in a small city or a university campus. Audikana et al. (2017) discussed the challenges in the implementing bikeshare in small cities, particularly usage rate, density, bikeshare network coverage, modal shifts, and the potential target population as well as strategies to improve system performance. Also, Nikitas (2018) surveyed attitudes toward bikesharing in a small Greek city and showed that respondents recognized the various environmental, health, and transportation benefits of bikesharing and in general, show a positive attitude toward using it. Similarly, Ashley (2012) examined the feasibility of a bikeshare program at Bridgewater State University through a review of other New England campuses with bikeshare systems in place and a stated preference survey of the campus community. Their results showed that the majority of survey participants (around 84%) would be interested in using a bikeshare system. More recently, Kutela and Teng (2019) investigated the impacts of campus characteristics and weather conditions on daily bikeshare trips at 25 US university campuses, between 2014 and 2018. They suggested that the number of faculty, staff and full-time students, as well as campus size positively influence the number of bikeshare trips within a university campus while the campus' distance to a central business district and severe weather events show a negative relationship with bikeshare demand.

Although many research studies have been performed on plans and strategies for future bikeshare systems, few studies investigated an existing system's usage pattern and demand factors in a small community context. This study seeks to fill this literature gap by analyzing the spatial and temporal distribution of bikeshare trips in and around the University of Maryland campus and determining the most significant factors influencing bikeshare demand. We investigated the effect of station location, station elevation, time of day and day of the week, weather conditions, and proximity to other bikeshare stations and amenities on bikeshare trip demand, trip length, and duration. The results shed some light on bikeshare demand among the student population given their flexible work schedules, travel patterns, and socioeconomic and demographic characteristics, which are different from the general population.

3. Study area

As a major educational and research institution of more than 40,000 students, the University of Maryland, College Park is one of the largest universities in the United States, with an area of 1335 acres. According to the Maryland Department of Labor, UMD is among the top five largest employers in the State of Maryland, with around 4658 academic staff, 5481 administrative staff, and around 41,200 students (Maryland - Major Employer Lists, n. d.). As a recent UMD transportation survey indicates, College Park is a highly auto-oriented campus, with a more than 80% drive alone mode share and less than 10% transit and non-motorized mode share.¹ However, as the campus is located in the heart of College Park's downtown with a dense, mixed-use urban form and high transit accessibility, it has great potential for active transportation to get to and around campus.

With eight on-campus stations and 16 stations near the campus, the UMD bikeshare system offers a quick and easy way to travel to and around campus and College Park (see Table 1 for a list of all stations and their activity during the study's time period). Ridership is growing fast, with more than 11,000 rides recorded in September 2018, more than double the rides in September 2017. This increase in ridership offers important environmental and health benefits for users and the campus community. It also helps campus transportation planners address significant parking space limitations created when several campus parking lots were recently redeveloped as buildings or open spaces. Promoting biking on campus would help UMD transportation officials to better manage parking space limitations as well as heavy congestion on and around campus during peak hours or during special events such as graduation ceremonies, sports, and games.

4. Bikeshare trips data analysis

4.1. Data description and processing steps

The bikeshare trip data for a 19-month period—June 2017 to January 2019—was obtained from Zagster, the UMD bikeshare program's operating company. This data provides point-to-point GPS trajectory information for all single trips between the 24 bike rental stations in College Park. There are 79,273 unique trips, each of them identified by a trip ID. The data shows that 3607 unique users have made an average of 22 trips. Each trip record consists of multiple attributes—information about the trip's date and time, and the location of the bike used in the trip. A total of 1,851,924 records are available for all trips, including all trip-related events such as start-event, end-event, on-hold, lock/unlock, and foreground/background ping events. The data is spatially and temporally analyzed to investigate the riders' behavior, such as trip origin/destination location densities, trip distance and duration analysis, trip start time distribution, etc. Data cleaning includes the following steps.

1. Ping locations are excluded from the trip records as we are interested in analyzing trips as a whole with origin and destination. The final dataset

Table 1

Bikeshare station activity during the analysis period.

On-campus stations				
Station name	Start trips (number of records)	End trips (number of records)	Average weekday demand	Average weekend demand
Eppley	6024	4860	10.7	6.2
McKeldin Mall	2673	2314	5.35	1.7
Mowatt Lane	3137	2603	5.95	2.4
North STEM	1215	1344	2.65	1.05
Northgate	3787	4169	7.5	5.35
South Campus	3951	3167	7.3	3.3
Dining Hall				
Regents Drive	5612	5482	12.05	3.35
Stamp Student Union	3001	1622	4.85	1.8
On-campus Total	29,400	25,561	56.3	25.2
Off-Campus Stations				
Art Walk Station	397	496	1.0	0.15
Berwyn Trolley Trail	2479	2393	4.6	3.2
Cambria Suites	36	43	0.1	0.05
City Hall	3569	4404	7.35	5.7
College Park Metro	6524	7336	14.55	5.45
West				
Courtyards	918	1046	1.9	1.2
Greenbelt Metro	299	295	0.5	0.5
West				
Guilford Drive	2531	2729	4.95	3.45
Hollywood Shopping Center	639	659	1.15	1.1
Monument Village	1000	757	1.65	1.2
Queens Chapel	573	407	0.95	0.65
Ritchie	1686	1732	3.4	1.75
Riverdale Park	532	561	1.15	0.45
The Hotel	533	523	1.15	0.35
University View	3826	4308	7.75	5.15
Wells Parkway	349	459	0.65	0.8
Off-campus Total	25,891	28,148	52.8	31.25
Not a Station	8400	9982	19.5	6.9

- includes start/end trip location, time, and date for each unique trip.
- Records with missing dates, times and location information are excluded from the dataset.
- Trips that started or ended outside the city (stations bounding box) are excluded from the dataset.
- Start and end information is estimated for records missing explicit start/end events. Basically, we assumed the first/last locking event as the actual start/end of the trips. To be precise, 17,341 trips do not have explicit start/end information, and when possible, the alternative events are used as a proxy. This practice has a small and negligible impact on the analysis since the average time difference of the unlock/lock events and actual start/end events are only about 4 s for the records containing both the actual start/end trip and first/last un/locking events.
- Trip duration is calculated using the start/end trip date and time. The records with trip duration less than or equal to 2 min are also excluded from the dataset as we assumed these records are unlikely to be actual trips and are most likely recorded as someone unlocks the bike and returns it as he/she changes their mind. Indeed, 1524 trips were excluded from the dataset by performing this step. To test this assumption, we assigned stations to these trips and found out that there were only five trips that did not start and end at the same station and were actual two-minute trips.

The final dataset, after cleaning steps, includes 63,692 trip records between June 14, 2017 and January 14, 2019. The bike station coordinates from the Zagster website were extracted to assign each trip record to a specific bike station. We then cross-referenced station locations with coordinates of the start-events and the end-events in our refined dataset and assigned two stations to each trip ID—one as the trip's start-station and the other as its end-station—if the respective coordinates were within 0.08 miles buffer of any of the stations. From the 63,692 trip records,

¹ UMD Department of Transportation Services: <https://transportation.umd.edu/>

49,707 records could be assigned to one of the 24 Zagster stations with both start and end. The remaining records are scattered in locations too far from any one of the existing 24 docking stations, which probably correspond to locations where the biker had stopped for a long period of time, without returning the bike, but there was no bike station nearby.

Additional steps were taken to integrate the bikeshare trip data with other information such as elevation, historical weather conditions, and land use. The historical daily weather information for the studied time period was acquired from NOAA's National Centers for Environmental Information (NCEI), collected from Washington's Reagan National Airport station, the closest station to our study area.

4.2. Spatial effect analysis

The effects of elevation, station location, and proximity to other stations, UMD shuttle bus stations, and destinations such as the Adele H. Stamp student Union were analyzed. Current stations and their bike accommodation capacities are shown in Fig. 1(a), which also illustrates information on each station's area type, UMD and WMATA bus stations, Metro stations, sport activity centers, university-affiliated buildings, and main campus borders. Fig. 1(b) provides a visual overview of bike demand across campus. The total number of trips for each station is shown with filled circles; the size of each circle is proportional to the number of trips originated from the station.

This spatial visualization indicates that many trip start locations are scattered all around the campus (gray dots), not necessarily on or close to docking stations. These trips probably correspond to locations where the biker had a stop on the way, but there was no bike station. A few clusters of trip start for these trips are indicated by gray hollow circles in Fig. 1(b). The weighted central point of these clusters can be used to identify the potential locations for new stations if an expansion plan is considered.

An example of these clusters is dense trip start records east of the Eppley Recreation Center where there is a significant distance between Eppley bike station and the recorded cluster. Some of these clusters (e.g. two adjacent clusters between Northgate and Regent Drive stations) show large number of trip start records which intuitively raises the idea of establishing new stations or relocating the stations to locations with better accessibility that reduces bikers' walking distance.

Table 1 lists both on- and off-campus bikeshare stations and presents the total activity at each station (both check-outs and drop-offs) for the entire analysis period. As it indicates, among the on-campus stations, College Park Metro, Regents Drive, and Eppley are the top three stations with the highest demand. This is expected, as depicted in Fig. 1(a), the College Park Metro and Regents Drive stations are located next to many major campus buildings such as the UMD department of transportation and the Regents Drive garage, as well as the major on-campus transit hubs, namely College Park Metro station and the main university shuttle bus station. Eppley station is located next to the university's recreation center, which is a popular destination and attracts individuals from all around the campus to use the service. Also, since the recreation center is relatively far from other buildings on the campus (see Fig. 1(b)), riding a shuttle or bike to the gym can decrease the travel time significantly.

Table 1 also shows that there are around 8000–10,000 records of the trips originated from or ended in locations other than an installed docking station. These start and end trip records are probably related to cases when people put the bikes on-hold to come back to and continue their trips. Therefore, these locations could be considered as potential candidates for additional docking stations, in case of the system's expansion.

Fig. 2 visualizes the origin-destination (OD) trip matrix for all trips regardless of time of day and day of week, with the diagonal showing the trips starting and ending at the same station (i.e., round trips). The size of squares represents the number of trips made for each OD pair and identifies

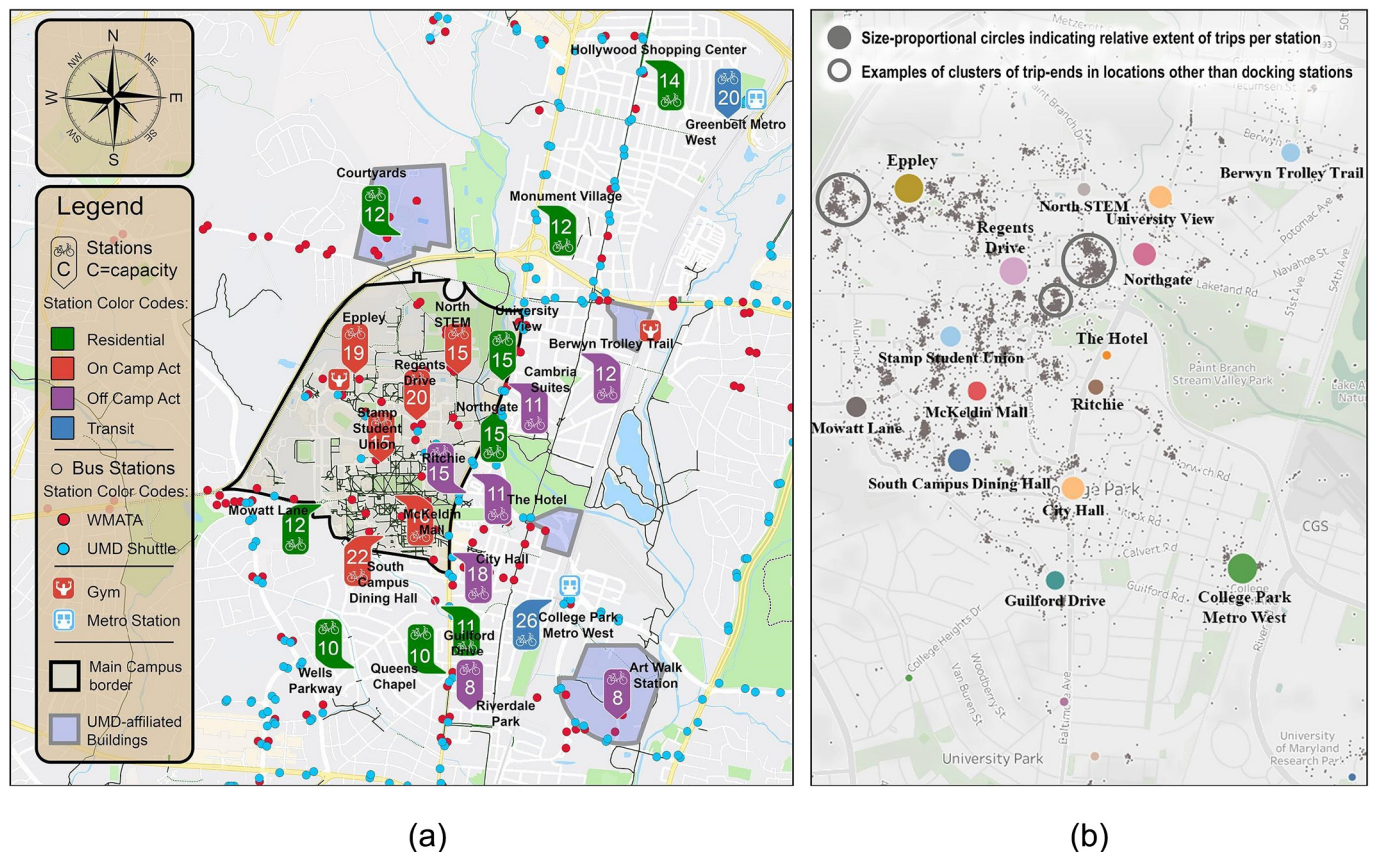


Fig. 1. (a) Geo-demographic information for 24 stations. (b) Start of trip distribution across campus for stations within or adjacent to the main campus. The size of the circles is proportional to the total number of trips originating from each station.

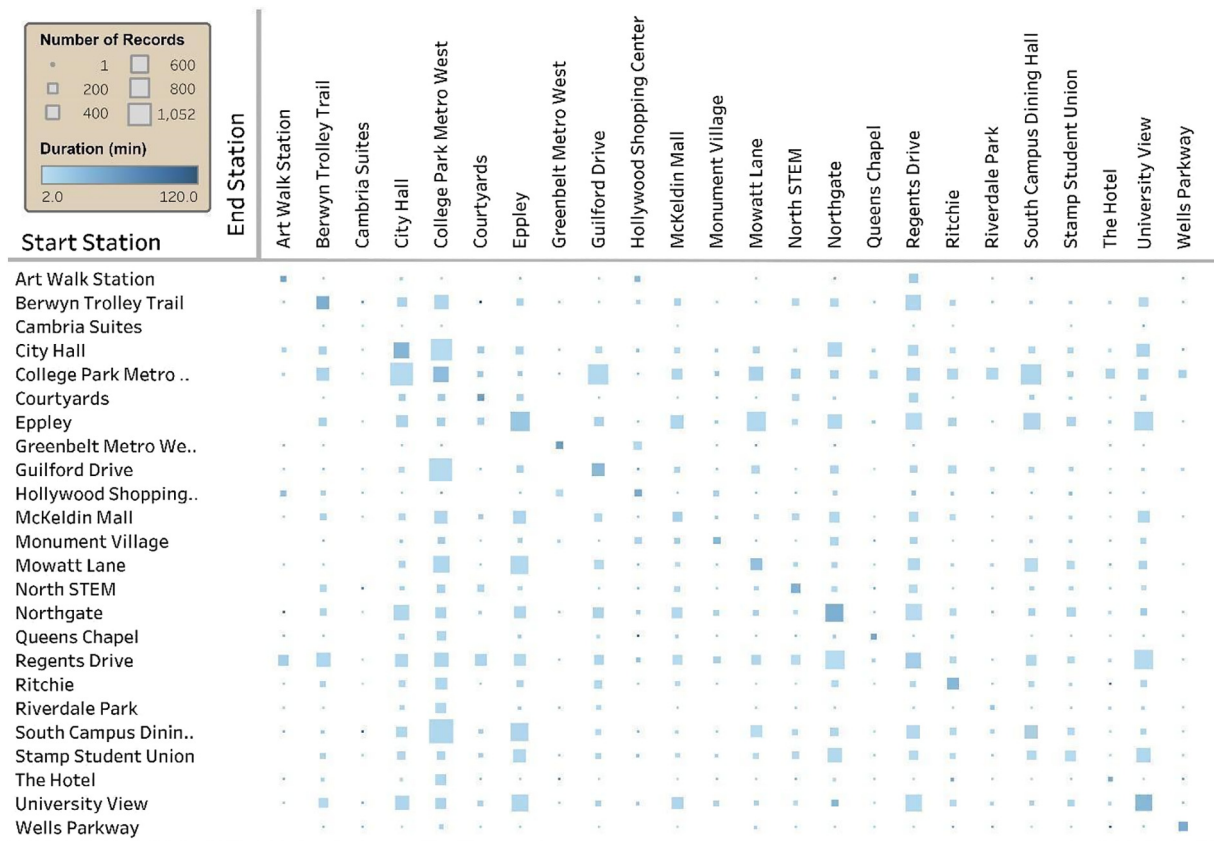


Fig. 2. Origin-destination trip matrix. The size and color intensity of the rectangles illustrates the number of trips and trip duration, respectively.

popular bike origins and destinations, on- and off-campus. This figure shows that College Park Metro West is the most popular station for both origin and destination. Other popular stations are Eppley (next to the recreation facilities) and Regents Drive.

Based on Zagster's station location map,² there are eight stations located on-campus and 16 stations located off-campus in the city of College Park (all within two miles of campus boundaries). Table 2 summarizes the number of trips between each OD pair (i.e., within campus boundaries, outside campus boundaries, on-campus to off-campus, and off-campus to on-campus trips). It indicates that off-campus to on-campus trips have the lowest frequency within the study's time period, while trips between on-campus stations have the highest frequency (almost double off-campus to on-campus trips). Trips within campus boundaries are also relatively high compared to other OD pairs. This clustering of trips based on station location is important for better understanding of travel patterns and bikeshare system's demand.

Fig. 3 shows the total number of trips for the four possible combinations of origins and destinations, over different hours of the day during weekdays and weekends. It indicates that:

- There is no typical morning peak period (6:00 am–9:00 am) demand for any of the directions.
- There is a spike in the number of trips made to off-campus at 12 pm suggesting lunch time demand, and a similar peak around 12:30 pm for trips toward on-campus stations suggesting travel demand for attending afternoon classes.
- Peak demand for on-campus to off-campus on weekdays for afternoon trips is at around 8 pm–9 pm, which is different from the regular afternoon traffic peak period (4 pm–7 pm).

- The overall demand trend is almost the same on weekends but at a smaller scale.

As it is indicated in Fig. 3, the travel pattern for the campus bikeshare system is different than that of large community bikeshare systems. In large city systems, as indicated in previous studies, peak demand occurs during regular traffic rush hour periods in both morning and afternoon, although the afternoon peak period sees higher demand than the morning peak period (Rudloff and Lackner, 2014; Faghih-Imani and Eluru, 2016). Also, in large bikeshare systems most weekend demand occurs during the daytime (Xie and Wang, 2018) while overall weekend demand follows the same trend as weekday demand in College Park only with lower volume.

4.2.1. Analysis of trip duration

As part of this analysis, we investigated trip durations between different stations. The blue color intensity for each square in Fig. 2 indicates the average (median value) of trip duration between each OD pair. Since there are outliers with significantly longer durations in our data, we have used median values as summary statistics instead of the mean value. OD pairs with fewer than 30 trip records have been omitted. Most of the OD pairs have a travel time of less than 10 min; the longest trips appear on the

Table 2
Summary statistics for four different origin-destination combinations.

Start station	End station	Average elevation difference	Number of records
Off-campus	Off-campus	0	15,150
	On-campus	13	8630
On-campus	Off-campus	−14	11,234
	On-campus	−1	14,693

² www.zagster.com

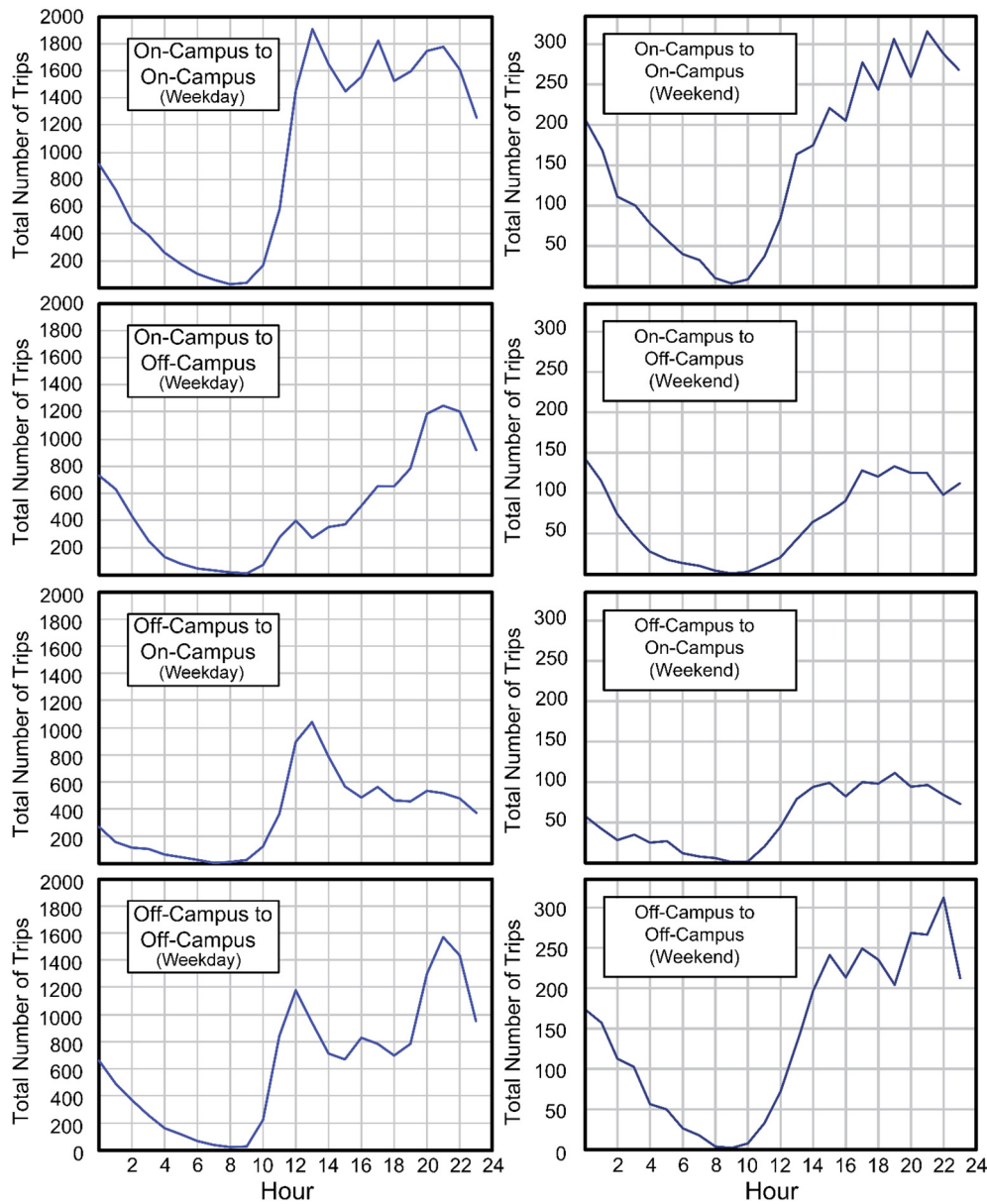


Fig. 3. Total number of trips for eight combinations of off-campus and on-campus origins and destinations, during different hours of the day, on weekdays and weekends.

main diagonal, meaning that users have most likely taken the bike for an activity outside campus routes.

We also see that trips which start and end at the same station (i.e., round trips) are longer in duration. Among these round trips, those that start and end at Greenbelt Metro West have the highest median duration (56 min). That the maximum median of trip durations between different pairs is < 1 h could be due to the bike system's pricing scheme, which offers free one-hour rides on its monthly and annual plans.

The median duration between on-campus stations is 413 s (6.8 min), showing that bikes are used for short trips between different parts of campus, instead of walking to those places. Among these, trips that start and end at Northgate have the highest median duration of 41 min, while also being among the most popular on-campus routes, with 600 trips. Northgate station is located on the east side of the campus next to several student residential buildings. Median trip duration from on-campus to off-campus stations is 511 s (8.5 min), average trip duration from off-campus to on-campus stations is 560 s (9.37 min), and median duration from off-campus to off-campus stations is 505 s (8.42 min). On weekends, the

median trip durations are only a few minutes longer in each direction. However, as suggested by previous studies, large bikeshare systems experience trips of much longer duration on weekends, probably because most leisure trips occur during that time (Fishman, 2016).

4.3. Temporal effects analysis

Fig. 4 presents trips distribution by days of the week and month of the year. Fig. 4(a) presents demand variation in different months of the year using only 2018 records since the 2017 and 2019 data do not cover the entire year). The highest demand is in September and October when the new academic year starts, and the weather is pleasant for biking. In contrast, winter months experience a lower demand due to colder temperatures and holidays. Fig. 4(b) shows the total number of trips by days of the week and indicates that on-campus demand is lowest on the weekends, since no classes are held and overall, on-campus activity is reduced.

Table 3 shows the average number of trips in six-hour windows for all stations. This table aims to better understand how demand is distributed

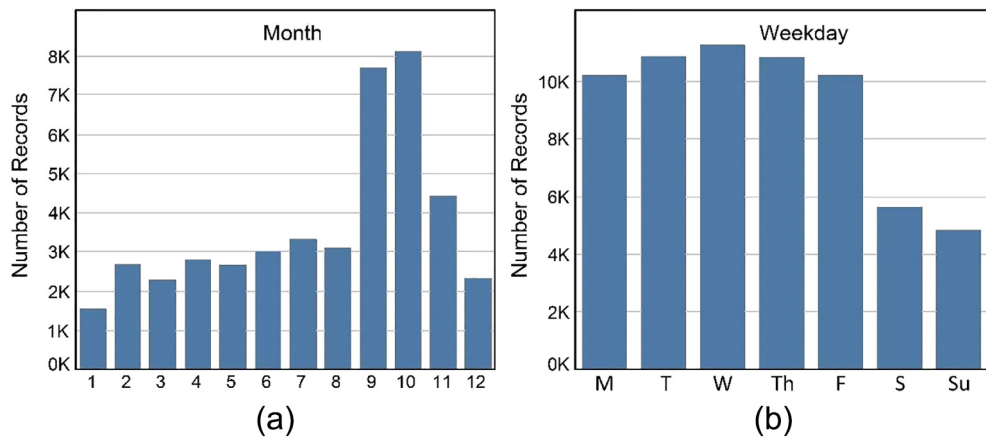


Fig. 4. Trip distribution by day of the week and month of the year for 2018.

among stations at specific times and whether there is a need to redistribute bikes during specific time windows based on expected demand. It also helps operators make more informed decisions about capacity and the number of available bikes at different stations during different times of day. A relatively large time-window was selected due to the relatively low daily use of some stations. When use is low, it is reasonable to assume that rebalancing is only needed every 6 h. As the data about network use efficiency grows, this analysis can be performed using smaller time-windows to allow for more effective rebalancing of bikes in the stations.

Fig. 5 shows how demand at each station is distributed across days of the week. In most stations, weekday demand is higher than the weekend demand. Indeed, the general trend observed in Fig. 4 (b) holds here, with only a few differences. For instance, the Hollywood Shopping Center does not show an obvious distinction between weekday and weekend demand. This is probably because this station is located near many retail stores and restaurants, making it a popular destination throughout the week.

Table 3
Average stations' demand distribution within different time windows.

Start station	12 AM–6 AM	6 AM–12 PM	12 PM–6 PM	6 PM–12 AM
Art Walk Station	0.008	0.037	0.159	0.565
Berwyn Trolley Trail	0.480	0.940	2.091	1.284
Cambria Suites	0.014	0.012	0.015	0.029
City Hall	1.385	0.803	1.766	2.950
College Park Metro West	1.424	2.103	3.480	5.613
Courtyards	0.199	0.317	0.710	0.549
Eppley	2.319	0.760	3.491	5.081
Greenbelt Metro West	0.101	0.031	0.087	0.360
Guilford Drive	0.474	1.277	1.607	1.538
Hollywood Shopping Center	0.141	0.342	0.455	0.298
McKeldin Mall	0.882	0.103	1.431	2.754
Monument Village	0.079	0.282	1.017	0.555
Mowatt Lane	1.060	0.408	1.814	2.785
North STEM	0.384	0.120	0.791	1.091
Northgate	1.596	0.424	2.025	3.280
Queens Chapel	0.046	0.277	0.435	0.350
Regents Drive	1.603	0.565	2.926	5.760
Ritchie	0.530	0.157	1.017	1.557
Riverdale Park	0.070	0.408	0.294	0.257
South Campus Dining Hall	1.046	1.147	2.070	3.379
Stamp Student Union	0.741	0.091	1.704	3.269
The Hotel	0.124	0.048	0.159	0.700
University View	1.135	0.696	2.485	3.083
Wells Parkway	0.062	0.130	0.213	0.271

□ For each time-window, the total number of trips started from each station is divided by 579 (number of days), to estimate average station demand.

4.4. Environmental effects analysis

To determine environmental effects on bikeshare demand, we analyzed the effect of temperature and topography (i.e., elevation) on trip frequency and duration. Fig. 6 illustrates the effect of average daily temperature and elevation differences between OD pairs on trip frequency. We first grouped the trip records based on average daily temperature, then counted the number of trips with similar dates in each temperature group, and finally, calculated the mean value of the trip counts. Fig. 6(a) plots the average daily demand against average daily temperature and indicates a positive relationship between temperature and bikeshare trip demand. This observation is consistent with previous research as well as our findings (Fig. 3(a)) that bikeshare trip demand is higher during the spring and summer months when the weather is nice, and the temperature is higher (Gebhart and Noland, 2014).

To analyze the relationship between weather conditions and demand, we computed the Spearman rank correlation coefficient of the daily demand with the average daily temperature, precipitation, and wind speed. The Spearman rank correlation is used because it does not assume linear relationship between the variables. To calculate the correlation, the average ride counts are aggregated into bins for each weather index and, the measurement variables are converted to ranks. The coefficient values for temperature and precipitation are 0.74 ($p < .0001$), and -0.39 ($p = .38$) respectively. We divided the wind speed data into two parts, one part includes the average ride counts when the wind speed is not strong, and the other part consists the average ride counts for the days with strong wind. A threshold of 10 m/s is set intuitively to calculate the correlations coefficients for each data. The value of 0.33 ($p = .07$) obtained for low wind speed and 0.57 ($p < .0001$) for high wind speed days. In general, the signs of the coefficients indicate that nice weather conditions (high temperature, low wind speed, and low precipitation levels) are associated with higher demand for bikes. This is expected and consistent with other studies about bikeshare systems in large cities (Gebhart and Noland, 2014). The relatively low correlation values reflect the fact that the demand is a more complex function of multiple variables, rather than being strongly dependent on a single variable such as low speed wind. Also, it is noteworthy that the weather data used in this study reflects regional average daily measurements, therefore, it is not possible to explain the demand fluctuation throughout a day entirely by those measurements. For instance, an hour of heavy rain cannot affect the demand of the entire day.

Additionally, we analyzed the frequency of trips by elevation difference between the origin and destination stations and found that trip frequency is the highest between station pairs with no elevation difference. The distribution of trip records for elevation differences in Fig. 6 is skewed toward the

WeekdayStation

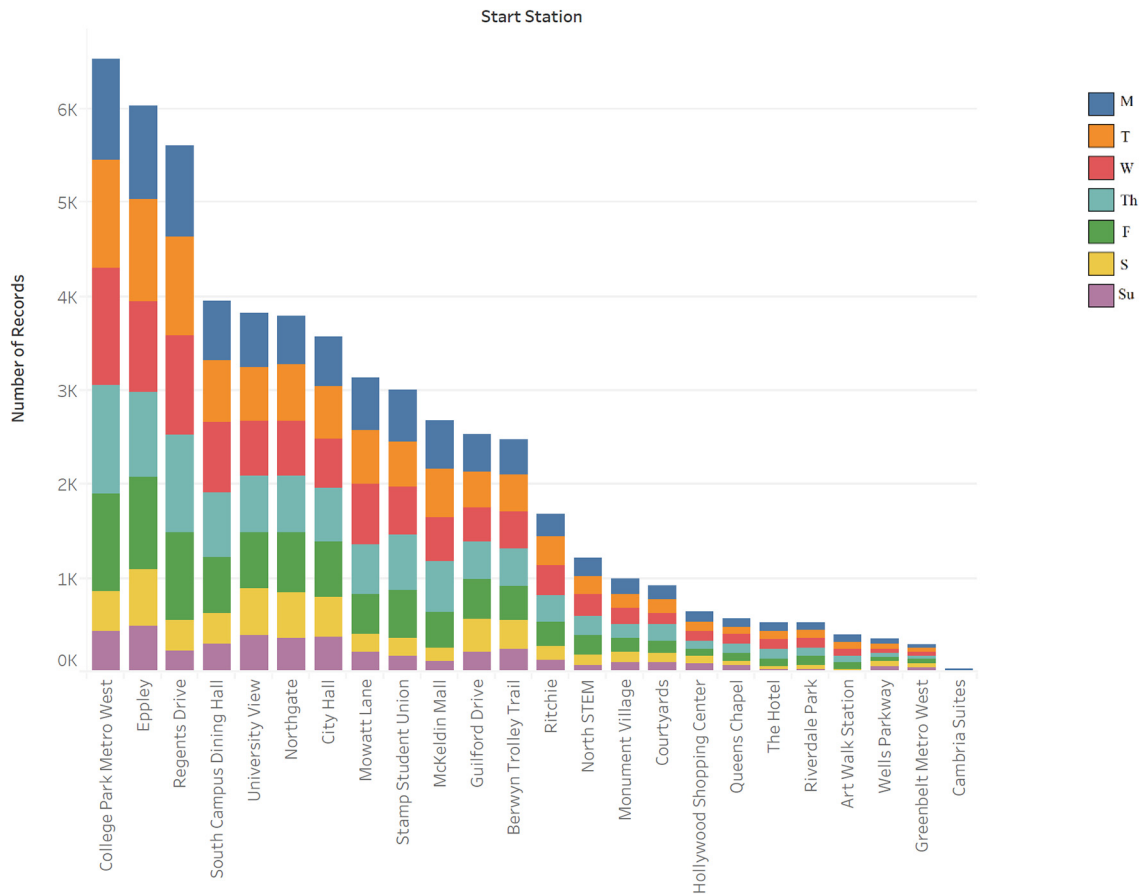


Fig. 5. Demand distribution at each station by the day of the week.

left (negative elevation differences), meaning that when there is an elevation difference between pairs of stations, the direction going toward the lower elevation is more frequent. In other words, the higher the elevation difference between OD stations, the fewer trips occurred between those OD pairs (see Fig. 6(b)).

5. Discussions and conclusion

In 2015, there were over 12 million full-time and about 7.7 million part-time college students in the United States, who account for approximately 6.2% of the total US population.³ Given their considerable proportion of the population and the fact that universities are usually among the largest local and regional employers, any sustainability effort including promoting and facilitating sustainable travel modes among university students and employees, becomes extremely important in society at large (Zhou, 2012; Carlos, 2003). Bikeshare is an innovative sustainable transportation mode that has been implemented in many large metropolitan areas as well as small communities. These emerging systems can potentially significantly influence travel patterns by providing a fast and efficient non-motorized mode while facilitating access to other modes such as transit. Therefore, understanding demand levels for existing bikeshare systems supports better planning and implementation of transportation systems within small communities.

This paper aims to understand the bikeshare trip demand at the University of Maryland, College Park campus and its surroundings from spatial, temporal, and environmental perspectives. Results confirm that factors

such as station location, proximity to amenities and student facilities, weather conditions and topography, and temporal factors all are significantly associated with the university's bikeshare demand.

The spatial analysis of trips reveals that the number of trips between two stations is about the same for both directions. Also, stations close to main transportation hubs have the highest demand (for both origin and destination trips). This shows that similar to larger bikeshare systems, the university bikeshares could also complement the existing transit system by facilitating first-mile/last-mile accessibility (Ma et al., 2015; Younes et al., 2019). Another spatial measure is topography and we find that trips occur more frequently between the higher-elevation to lower-elevation station pairs. This implies that as demand increases in the future, additional planning and effort toward relocating and rebalancing bikes might be necessary.

Temporal measures include trip duration, and results indicate that a considerable proportion of trips take about nine minutes or less, which implies that bikes are used for relatively shorter trip distances. On the other hand, there are a number of longer trips with a median duration of 41 min that mostly start and end in the same station (round trips). This implies a significant demand for bikesharing among individuals traveling off-campus and returning the bike to the same station.

As indicated in our time-of-day demand analysis, station use for on-campus to on-campus trips increases substantially between 12:00 PM and 12:00 AM compared to morning times. This is expected due to usually higher on-going, daytime activities on campus. The analysis of on-campus to off-campus trips and off-campus to on-campus trips shows an inverse relationship, which is also expected. The areas below the distribution curves for these two directions of trips are very close for 12:00 PM and 12:00 AM, which indicates that at the end of the day the demands for both sides are

³ Source: The National Center for Education Statistics- Accessed 6/21/2019- <https://nces.ed.gov/>

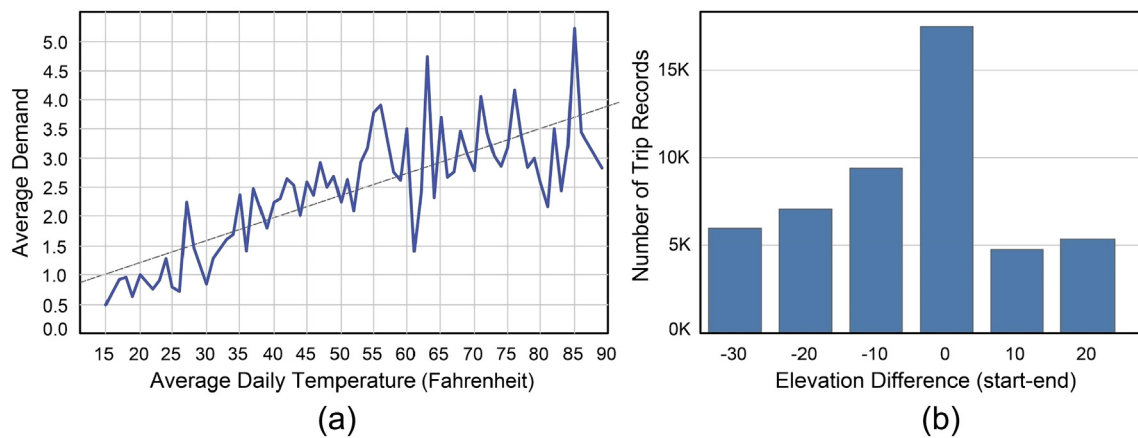


Fig. 6. Environmental effects analysis. (a) The average number of trips made per day in different temperatures. (b) The total number of trips made in different elevations (the difference of elevation from the start location to the end location).

satisfied, and the replaced bikes have been returned to their original stations. Moreover, the peak demand for off-campus to on-campus trips occurs around 12:00 PM, while the peak for the reverse direction occurs around 9:00 PM (see Fig. 3). This shows that the peak demand for biking on the campus is not consistent with the regular morning and afternoon peak periods of 6:00–9:00 AM and 4:00–7:00 PM. This confirms the need to analyze travel patterns and demand on university campuses separately from demand in a large city and metropolitan area context.

The temporal analysis also indicates that the highest demand for a six-hour period is between 6:00 PM and 12:00 AM. The highest value is for the Regent Drive station and is equal to 5.7 trips per six-hour period, while the capacity of this station is 20 docks.

Environmental factors also affect use rates. Our analysis showed a correlation between weather conditions (temperature, wind speed, and precipitation) and demand. Results show that demand is higher when temperatures range between 55- and 85-degrees Fahrenheit (in our case, during the summer months, September, and October). However, even though spring temperatures fall within that range, results show relatively lower demand during spring, implying that there might be other factors influencing demand in addition to weather conditions. For instance, higher demand during September and October might be due to the start of the academic year, which results in relatively higher activities across campus.

On the other hand, demand is observed to be relatively lower during January, probably due to winter's lower temperatures but also to the holiday season and university's closure between the fall and spring semesters.

Further research is needed to understand these demand differences fully. Moreover, the results indicate that there are several event points, which cannot be spatially linked to any stations. This might be because there are several high-activity-density areas across campus that aren't close to any bikeshare stations. Thus, because it's inconvenient to return bikes to a distant station, people lock and hold the bikes to prevent other users from accessing them. The analysis identifies a number of clusters of trip events at non-station points, which can be potential candidates for new stations, in case of system expansion. In identifying the best locations for additional stations, additional demand analysis and optimization models are required to maximize the system's usage and efficiency and minimize relocation costs, etc.

Our results, in general, show that despite similarities between the bikeshare demand in large cities—found in previous studies—and our campus bikeshare demand analysis, there are substantial differences, especially in trip duration distribution, temporal trip distribution pattern, demand peak periods, and bike turnarounds at different stations.

Despite these findings, challenges remain to understanding bikeshare demand analysis in a university campus context. For instance, analyzing the interactive effects of changes in bikeshare demand on other transportation modes requires triangulated data. The demand data for other modes

should be obtained for the same spatial and temporal points, and comparisons should be made between different modal shifts. For example, the use of a bikeshare system could be improved by increasing the capacity of existing stations, expanding the system to the areas with the potential for new stations, and offer incentive programs like reward points for using the bikes for daily commuting or for relocating bikes between stations to support rebalancing the system. Also, bikeshare planners and operators could consider the stations' dynamic capacity, especially during the high-demand months of year, as well as dynamic relocation of stations based on temporal demand changes across different parts of campus.

Moreover, with more data, future research could focus on the effect of bikeshare programs on parking demand and driving and congestion across university campuses to support more efficient transportation planning and management within small communities.

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Update

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Erratum

Erratum regarding missing Declaration of Competing Interest statements in previously published articles



Declaration of Competing Interest statements were not included in the published version of the following articles that appeared in previous issues of "Transportation Research Interdisciplinary Perspectives".

The appropriate Declaration/Competing Interest statements, provided by the Authors, are included below.

1. "Unsafe motorization: A clog in the wheels of sustainable transportation" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 6: 100153] <https://doi.org/10.1016/j.trip.2020.100153>

Declaration of competing interest: The authors were contacted after publication to request a Declaration of Interest statement.

2. "An exploration of policy knowledge-seeking on high-volume, low-carbon transport: findings from expert interviews in selected African and South-Asian countries" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100117] <https://doi.org/10.1016/j.trip.2020.100117>

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3. "Agent-based vulnerability assessment at airport security checkpoints: A case study on security operator behavior" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100139] <https://doi.org/10.1016/j.trip.2020.100139>

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4. "The effect of COVID-19 and subsequent social distancing on travel behavior" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100121] <https://doi.org/10.1016/j.trip.2020.100121>

Declaration of competing interest: The authors were contacted after publication to request a Declaration of Interest statement.

5. "Air quality and fossil fuel driven transportation in the Metropolitan Area of São Paulo" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100137] <https://doi.org/10.1016/j.trip.2020.100137>

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6. "The ultimate smart mobility combination for sustainable transport? A case study on shared electric automated mobility initiatives in the Netherlands" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100129] <https://doi.org/10.1016/j.trip.2020.100129>

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7. "A framework for end-to-end deep learning-based anomaly detection in transportation networks" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100112] <https://doi.org/10.1016/j.trip.2020.100112>

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8. "Ethical decision making behind the wheel – A driving simulator study" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100147] <https://doi.org/10.1016/j.trip.2020.100147>

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9. "Population size and transport company efficiency – Evidence from Czech Republic" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 6: 100145] <https://doi.org/10.1016/j.trip.2020.100145>

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10. "Toward sustainable travel: An analysis of campus bikeshare use" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 6: 100162] <https://doi.org/10.1016/j.trip.2020.100162>

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11. "Responsible Transport: A post-COVID agenda for transport policy and practice" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 6: 100151] <https://doi.org/10.1016/j.trip.2020.100151>

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12. "Distracted by "distracted pedestrians"?" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100118] <https://doi.org/10.1016/j.trip.2020.100118>
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17. "How COVID-19 and the Dutch 'intelligent lockdown' change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 6: 100150] <https://doi.org/10.1016/j.trip.2020.100150>
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18. "Interprofessional collaboration to promote transportation equity for environmental justice populations: A mixed methods study of civil engineers, transportation planners, and social workers' perspectives" [Transportation Research Interdisciplinary Perspectives, 2020; Volume 5: 100110] <https://doi.org/10.1016/j.trip.2020.100110>
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