Bicycle Parking Analysis Using Time Series Photography

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ABSTRACT
Bicycle parking data and analysis are necessary for evaluation of facility designs and parking plans, and for analysis of bicycle use more generally; they inform efforts to promote bicycle use, and provide direction for policy-makers and planners. However, there is a lack of research and data related to bicycle parking, and no standardized methodology for data collection. Measures such as duration and turnover have long been identified with vehicular parking studies, but have not been standardized in the literature related to bicycle parking.

This paper begins to fill this research gap by proposing a methodology for collecting detailed bicycle parking data. This methodology makes use of digital photography to capture parking data over a period of time, including arrival and departure times, parking durations, and turnover rates. This paper documents a trial data collection, and suggests ways in which the data can be used to answer specific research questions. In addition, the authors evaluate the feasibility of the proposed methodology, quantifying the work effort needed to perform the collection and analysis. They conclude that the methodology may be used in further academic research related to bicycle parking, and may provide valuable information for universities and public transportation agencies as they plan for, monitor, or improve bicycle parking facilities.

Keywords: bicycle parking, bicycle planning, data collection, bicycle infrastructure, barriers to cycling, active transportation, parking facilities

INTRODUCTION

In the US, bicycling is increasingly regarded as an important and underutilized mode of transportation, and municipalities and institutions have set goals for increasing the bicycling mode share. Research suggests that the provision of parking facilities alone has only a small positive causal effect on bicycle use (*1*). However, the provision of ample and secure bicycle parking has been a crucial part of successful constellation efforts to increase bicycle use in the US and Europe (*1*, *2, 3*). Similarly, the lack of adequate and secure parking is often cited in stated preference studies as a barrier to bicycle use (*4*, *5*).

Bicycle parking data and analysis are necessary for evaluation of facility designs and parking plans, and for analysis of bicycle use more generally; they inform efforts to promote bicycle use, and provide direction for policy-makers and planners. However, there is a general lack of research and data related to bicycle parking, and no standardized methodology for data collection. Measures such as duration and turnover have long been identified with vehicular parking studies and viewed as essential to understanding and predicting vehicular trip generation –but these measures have not been utilized in the study of bicycle parking or trip-making.

This paper begins to fill this research gap by proposing a methodology to collect detailed bicycle parking data. This methodology makes use of digital photography, a widely available and inexpensive technology, to capture parking data over a period of time. Detailed data including arrival and departure times, parking durations, and turnover rates can be collected in this way. The authors document a trial data collection, and suggest ways in which the data can be used to answer specific research questions. In addition, the authors evaluate the feasibility of the proposed methodology, quantifying the work effort needed to perform the collection and analysis.

BACKGROUND

Even within the field of bicycle-related research, parking issues have received scant attention: a 2005 nation-wide review of pedestrian and bicycle data collection and facility inventory efforts included no research on bicycle parking activity or utilizing bicycle parking data, and little information related to the planning, construction, or inventory of bicycle parking facilities (*5*). Nevertheless, there is a body of literature relevant to this bicycle parking investigation, and it can be loosely grouped into three categories: policies, programs, and infrastructure design guidelines; bicycle parking studies; and vehicular parking study methodologies.

Policies, Programs & Design Guidelines

Throughout the twentieth century, public bicycle parking in the US was largely confined to areas designated for pedestrian use—sidewalks—and occasionally to areas in parking structures not suitable for automobiles. In other words, bicycle parking was not a discrete, well-established or uniformly defined use of space. Where dedicated facilities have existed, they were frequently plagued with inefficient and unsafe designs. In some areas, adequate supply of dedicated bicycle parking simply did not exist. This has been illuminated in recent years as individual pole-mounted parking meters have been replaced by multi-space parking kiosks. Bicyclists in cities across the country found themselves with no place to park, and local governments responded in a variety of ways—from adapting old poles to dedicated bicycle parking, to piloting use of new solar-powered individual-space meters with electronic payment options, to launching municipal bicycle parking programs (*7*, *8*).

Universities were among the first in the US to formalize institutional policies, programs, and research related to bicycle parking. This may be the result of their limited sizes, youthful student populations with lower rates of car ownership, and academic orientation. More recently, cities across the country have also recognized the importance of bicycle parking: integrating bicycle parking into municipal codes and plans, setting standards for bicycle parking, formalizing the provision of public bicycle parking, and instituting bicycle parking requirements for new or existing buildings. New York City, established zoning requirements for bicycle parking in residential and workplace construction in April 2009 (*9*). More comprehensive lists of bicycle programs addressing parking concerns are maintained by a variety of organizations, including the Association for the Advancement of Sustainability in Higher Education (*10*), the National Center for Bicycling and Walking (*11*), and the National Association of City Transportation Officials (*12*).

In addition to formal ordinances and programs, bicycle parking facility design guidelines are available from numerous sources, including the Federal Highway Administration (*13*), professional organizations such as AASHTO (*14*) and the Association of Pedestrian and Bicycle Professionals (*15*), and non-profit bicycle advocacy groups such as the Victoria Transport Policy Institute (*16*) and the Initiative for Bicycle and Pedestrian Innovation (*17*). These guidelines typically indicate minimum space requirements for bicycle parking and suggest steps to improve parking conditions through policy and program implementation. Beyond the facility inventory, there is no discussion of data collection.

Bicycle Parking Studies

There is a body of academic work related to bicycle parking, but a recent review by Pucher, Dill, and Handy found “few rigorous studies of the impacts of bike parking on bicycling levels” (*1*). Some existing studies have focused on the impacts of increased bicycle parking at transit stations on commuter mode share. Other studies have been performed by universities and municipalities in conjunction with the programs discussed previously. Most of these studies focus on the allocation of resources or progress toward established goals.

In general, these bicycle parking studies have employed two methods: counts and surveys.

Bicycle Parking Count Data

The University of Washington (UW) has published a report on campus bicycle parking every year since 2000 (*18*). These analyses have relied on annual campus-wide bicycle counts, each conducted during a single four-hour, mid-day period on a sunny, mild spring day. This methodology is an attempt to measure accumulation during a peak demand period, and provides a snapshot of bicycle parking activity; herein this method is referred to as the snapshot approach. The snapshot approach is roughly equivalent to vehicular accumulation studies such as the ITE trip generation data collection (*19*). It has been widely used in university and municipal studies, such as those done by the New York City Department of City Planning (*20*), the Portland Bureau of Transportation (*21*), and Portland State University Transportation and Parking Services (*5*).

Using the snapshot data, “utilization rates” are typically generated by dividing the number of bicycles parked by the design capacity of the parking facilities. Utilization rates for individual parking facilities and larger areas, including entire university campuses, are commonly reported and used to instruct changes to parking plans and facilities. In their 2009 Bicycle Parking Assessment, program managers at University of Colorado at Boulder appear to have improved on the standard snapshot method by performing multiple counts over the course of a month, using the highest counts at each location to determine peak demand (*22*).

The snapshot approach has several advantages. Used year-to-year, it can provide information about trends in overall bicycle use. It can also provide some information about user preferences. For example, UC Boulder's 2009 Assessment (*23*) grouped parking facilities based on their proximity to building entrances, and reported anecdotally that when utilization rates were above 75 percent, the number of "errata" bicycles—those found locked to nearby benches, railings, street signs—increased dramatically. As a result, the UC Boulder authors recommended setting a "target utilization rate" at 75 percent of the facility design capacity.

The snapshot approach also has drawbacks. It cannot provide arrival or departure information, or count the number of individual parking events over a period of time. Sample sizes and experimental controls are limited, and the data collection can be cumbersome and require interpretation in the field. Addressing these shortcomings was an objective in the development of the time-series methodology.

Bicycle Parking Survey Data

Surveys are often used in conjunction with the snapshot approach. For instance, UW surveys the renters of its 600 bicycle parking lockers to obtain utilization data which is incorporated into the campus-wide statistics (*18*). PSU Transportation and Parking Services uses surveys to glean both broad and deep information by conducting an annual bicycle survey, and biennial student and employee commute surveys (*5*).

Survey data have two significant limitations. First, surveys generally rely on individuals' perceptions to report factual information, such as travel time to the parking site, and arrival and departure times, thus the data are prone to error. Second, respondents to topical surveys typically constitute a self-selected group, and bias between this group and larger populations is not clear. Some bias is eliminated by over-sampling select subgroups, or by heuristic analysis using multiple surveys. For example, the PSU bicycle survey mentioned above is performed over the course of a week, where response cards or fliers are attached to as many bicycles on campus as possible directing potential respondents to an online survey. Respondents in this case are self-selected. In contrast, the PSU student and employee commute surveys randomly select and contact potential respondents directly. Despite these shortcomings, surveys can provide useful information about bicycle parking. Of note here, lack of secure parking is one of the most frequently cited barriers to bicycle use for transportation (*5*, *24*).

One current topic of inquiry is the economic impact of bicycle parking. The city of Portland, OR, has a growing program that repurposes curbside automobile parking spaces for bicycle parking. These so-called "bike corrals" are intended to meet the demand for bicycle parking and to remove bicycle parking congestion from pedestrian zones and store fronts, but what are the economic impacts of bike corrals? A 2010 report indicates that in general owners of businesses near bike corrals perceive increased patronage by bicyclists, and increased demand for bicycle parking (*25*). This finding corroborates the earlier supposition that the provision of parking may help promote bicycle use. However, the study author specifically notes that he was unable to determine whether the business owners' perceptions of increased traffic and patronage were accurate. A new method is needed to address these questions.

Vehicular Study Methodologies

Not surprisingly, vehicular parking studies informed the development of the proposed methodology. Accumulation, volume, duration, and turnover, are well-established measures of vehicular parking activity and objects of routine data collection and study (*26*). Categorization of parking activity by duration is also standard practice, though specific definitions such as short-, mid-, and long-term vary. All of these measures are relevant to bicycle parking, but only peak accumulation appears to have not been widely used related to bicycle parking. As a prerequisite to discussion or development of a methodology, the authors adapted definitions of vehicular parking measures for use with bicycles, with the results shown in TABLE 1.

TABLE 1 Well-defined measures commonly associated with vehicular parking studies, adapted for bicycle parking analysis

Capacity (*C*)	The maximum number of parked bicycles a facility is designed to accommodate at any given time.
Accumulation (*A*)	The number of bicycles parked at a facility at a specific time.
Volume (*V*)	The number of unique instances of a bicycle being parked at a facility over a period of time.
Duration (*D*)	The amount of time a specific bicycle is continuously parked at a facility.
Turnover (*T*)	The ratio of volume to capacity for a facility: $T = V / C$.
Occupancy (O)	The ratio of accumulation to capacity for a facility, expressed as a ratio or a percentage: $O = A/C$

Additional considerations were found in the Boston Metropolitan Area Planning Council's description of using license plate numbers as unique vehicle identifiers (*27*), and in Syrakis's and Platt's documentation of what appears to be one of the first uses of aerial photographs in parking studies (*28*). Finally, the authors noted several instances in which data collection was found to be time-consuming, expensive, and a limiting factor. This was particularly common in the case of bicycle-related studies (*1*, *27*).

METHODOLOGY

Based on the review of literature, the following were determined to be requirements of any new methodology: (1) reduce self-selection bias and perceptual error, (2) the ability to capture duration, accumulation, and volume over time; and (3) a high degree of efficiency in terms of cost, researchers' time, and equipment.

Digital photography provided an ideal tool to capture raw data under these requirements. Photos taken from the same position at regular time intervals allow for the identification of individual bicycle arrival and departure to within a particular time interval. Additionally, the data can be used to approximate parking duration derived from the arrival and departure times.

Study Area

The study area included 35 bicycle parking areas with a total of 368 bicycle parking spaces, all on the campus of PSU. Though parking area capacities varied, each parking area used the "inverted-U" rack as a fundamental unit—that is, each area was composed of one or more "inverted-U" racks. Because this is a feasibility study, rack locations were selected to reflect a variety of parking conditions, from isolated curbside racks, to large groups of racks adjacent to building entrances. Capacities of the parking areas ranged from two (for a single rack), to 70.

It was also important to select racks that were within a reasonable walking distance of each other to ensure efficient data collection. After the racks were selected, 49 data collection vantage points were identified and ordered, and a data collection route was previewed. For high capacity parking areas, multiple photographs were deemed necessary. The study area, selected rack locations, and photograph vantage points are shown in FIGURE 1.

Bicycles parked at locations other than dedicated racks, i.e. street signs, railings, etc., were not counted. Capacity is not well-defined for these informal facilities and it is difficult to determine whether these facilities are used as preferred parking or overflow parking. The researchers felt that attempting to capture this data was likely to introduce bias into the results.

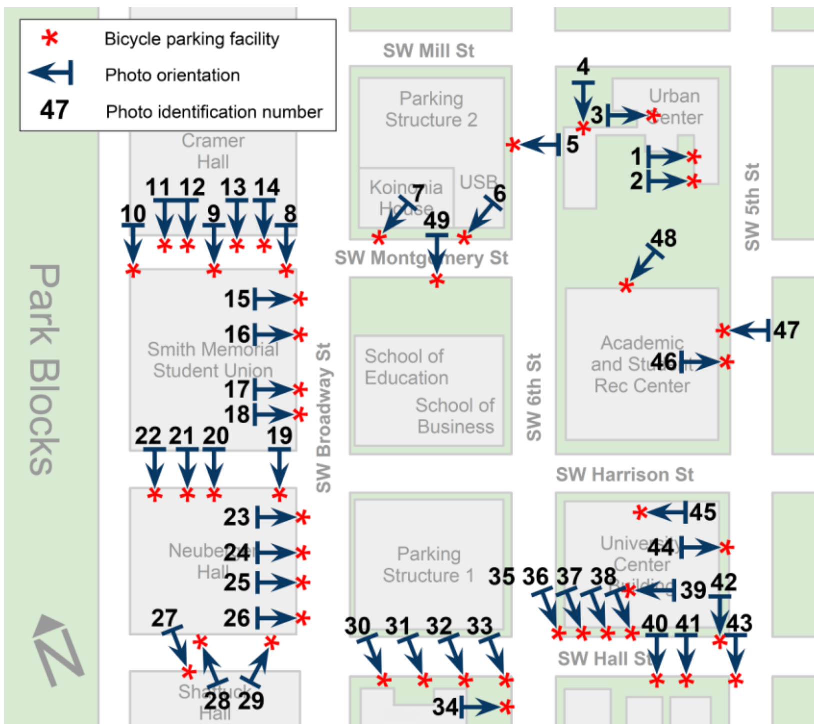

FIGURE 1 Study area, with photograph locations and identification numbers.

Data Collection

The study period was 12 hours, 8:00 AM to 8:00 PM, with a time interval of one hour between photographs. Data collection was performed on Thursday, November 5th, 2009, weather was overcast with sporadic light rain.

Every hour, a research team member traveled the designated route, taking the prescribed photographs in chronological order. By following the predetermined route and photo sequence, photos taken at each individual rack were approximately one hour apart. Timestamp recording ensured that the photos were correctly identified. **FIGURE 2** presents a sample of photos taken between 8:00 AM and 12:00 PM at photo location 03.

FIGURE 2 Sample photos from location 3.

TABLE 2 Data collection matrix B for location 3; $b_{i,t}$ = 1 indicates the presence of bicycle *i* at time *t*

Bike number (*i*)	**Rack position and identifying notes**		**Time (*t*)**												
			08	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	12	White w/basket	1	1	1	1	1	1	1	1	1	1			
2	2	Pink/white				1	1	1	1						
3	6	Black mtn bike				1	1	1	1						
4	8	Yellow.grey road bike				1	1	1	1	1	1	1			
5	3	Blue mtn bike						1	1	1					
6	4	Red/white						1	1	1	1				
7	5	Blue w/crate						1	1	1					
8	9	White mtn bike						1	1	1	1	1	1	1	
9	10	Blue road bike						1	1	1	1	1			
10	11	Blue/black mtn bike						1	1						
11	6	White w/helmet							1	1	1	1	1		
12	11	Brown/yellow								1	1	1	1		
13	2	Pink/white									1	1	1	1	1
14	5	White/teal										1	1		
15	12	Black road bike												1	1

Following field collection, a web-based application was used to store, tag, and sort the photos by time and location. A parking event record was created for each bicycle observed, along with descriptive notes, to comprise a matrix **B**, shown as TABLE 2. Indicator variables $\boldsymbol{B}_{i,t}$ were used to record the presence of bicycle $\boldsymbol{i}$ at time $\boldsymbol{t}$. Defining a "parking event" as the arrival, presence, and departure of a bicycle at a parking facility ensured the linking of arrival and departure data, and allowed for additional analysis.

RESULTS

The parking event data was processed to obtain the desired measures, both for individual locations and the study area en masse. Calculations for some of these measures are illustrated in TABLE 3. In addition, turnover and occupancy ratio were calculated for each location, and arrival and departure times were identified for each individual parking event.

TABLE 3 Calculation of derived measures

Measure	**Calculation**
Accumulation for a particular location (*loc*) at time (*t*)	$A_{loc,t} = \sum_{\forall i} B_{i,t}$
Total accumulation across the entire study area at time (*t*)	$A_{T,t} = \sum_{\forall loc} A_{loc,t}$
Duration of an individual parking event (*i*)	$D_i = \sum_{\forall t} B_{i,t}$
Volume for a particular location (*loc*), and over the entire study area	$V_{loc} = \max(i)$,
Total volume over the entire study area	$V_T = \sum_{\forall loc} V_{loc}$

Volume and Turnover

The collected data revealed a total of 490 individual parking events (the total parking volume) over the 12 hour period, yielding an overall turnover rate of 1.33 parking events per space per day. Turnover rates for individual parking locations however varied from 0.0 to 3.0, suggesting that a comparative analysis of turnover rates based on facility characteristics may be a fruitful topic for future research.

Duration

The Portland Bureau of Transportation categorizes bicycle parking activity by duration: short-term is used to describe parking events lasting less than two hours, mid-term is for durations between two and four hours, and long-term is for durations greater than four hours (*29*). Using these categories, the breakdown of observed parking events is shown in FIGURE 3.

This information might be used, for example, to manage demand. The PSU bicycle program has received complaints about crowded parking near building entrances. Duration data might show that long term visitors utilize parking close to building entrances, and that long term visitors are more likely than short term visitors to be enticed to alternative parking locations by the provision of sheltered or secured parking; so it would be reasonable to suppose that provision of such amenities would reduce demand for parking close to building entrances.

It is worth noting here that the accuracy of the duration measure is determined by the length of the photo interval. For example, the interval in this study was one hour, and a parking event with a calculated duration of one hour (D = 1) theoretically had an actual duration between zero and two hours.

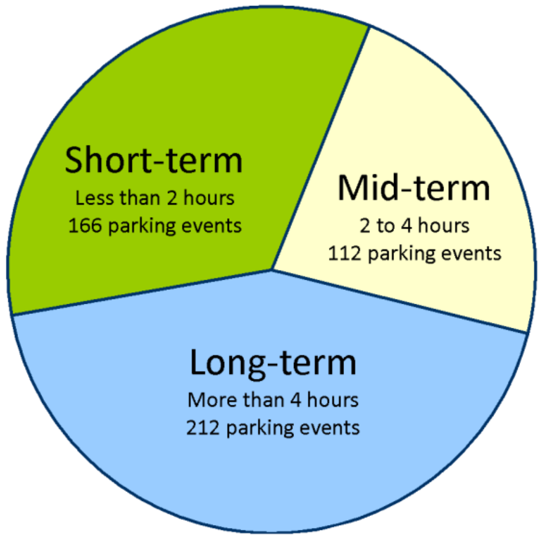

FIGURE 3 Duration of observed parking events.

Accumulation and Occupancy

Accumulation in vehicular studies can be plotted as a function of time. **FIGURE 4** shows study area accumulation data over the 12 hour study period. Interpreting this plot, it appears that even during peak accumulation there is still parking available, even allowing for turnover losses.

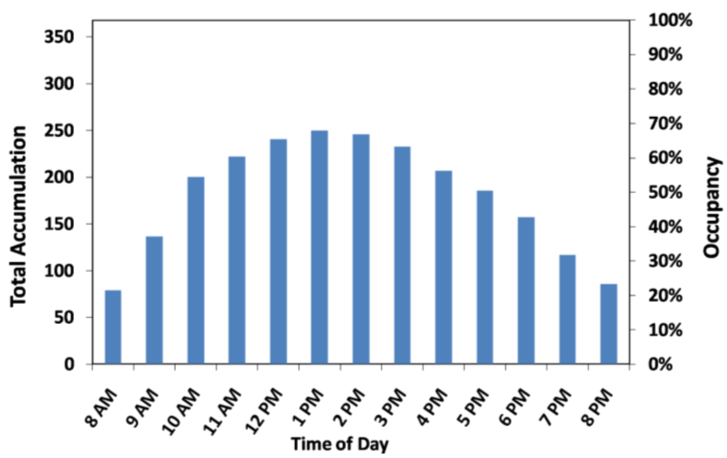

FIGURE 4 Accumulation and occupancy for the entire study area, as a function of time

Occupancy appears to be a useful tool for comparing specific rack locations. The authors observed that locations adjacent to popular campus buildings experienced particularly high occupancy rates. The Smith/Cramer courtyard, for example, had a peak occupancy greater than 100 percent. In contrast, the parking area on Montgomery Street, located 225 feet from entrances to Smith and Cramer Hall experienced no more than 25 percent occupancy throughout the day. These results are presented in FIGURE 5. These findings not only confirm the common thinking that users prefer to park close to their (assumed) destinations, they allow this preference to be quantified and potentially compared to other user preferences. Such analysis might lead campus planners to provide incentives at the Montgomery location that would attract long term users, as discussed previously.

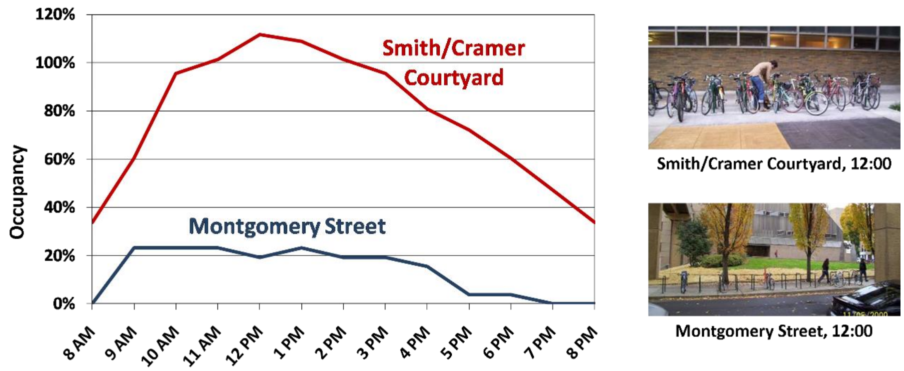

FIGURE 5 Occupancy rates for the Smith/Cramer courtyard parking area (photos 08-14, capacity 68) and for Montgomery Avenue parking area (photo 49, capacity 26) reveal wide variation, despite the fact that the two parking areas are 225 feet apart. Note: this chart is not cumulative—the Smith/Cramer courtyard exceeded design capacity during peak hours.

DISCUSSION

Based on the experience gained through the trial study, as well as the collected data and derived measures, the researchers found that the trial methodology met the established requirements, and had several advantages over previously existing methodologies.

Advantages

The time-series photographic method captured the intended measures and improved on the "count" method: A simple peak-hour count would have missed 240 parking events. A more thorough count of every bicycle appearing at all between 10:00 AM and 2:00 PM would still have missed 141 trips.

The photographic record is robust: it eliminates the need for counting and interpretation in the field, and may be mined for additional data in the future.

The data collection did not require expensive equipment or extensive training or expertise. The authors suggest that with minimal training the majority of this work could be performed by interns or students. Also, storage and processing of photos is less time consuming and less expensive than video monitoring.

The trial method is versatile. The photo interval can be adjusted to fit a wide variety of situations: a shorter interval might capture a coffee shop's customers' bicycle mode share, while a longer one could help identify seasonal or annual ridership trends. Further adaptation might be able to provide before-and-after analysis of new facilities and traffic enhancements.

Drawbacks

The trial method is not without flaws, however. For example: the accuracy of the duration measure is limited by the length of the photo interval, and the photo record may fail to capture any parking event shorter than the photo interval. It is up to the designers of a study to choose the appropriate interval for collection.

Arrivals and departures at specific locations may be correlated to particular events, such as transit or school schedules, which may introduce bias. In addition, the manual coding of data by multiple researchers may have introduced error. Future study may include an assessment of these or other sources of bias.

The trial study did not capture bicycles parked and locked to street signs, street trees, etc. Future studies would benefit from a standardized method for counting these bicycles, similar to the way that illegally parked motor vehicles are counted in motor vehicle studies.

It is unclear whether the methodology is time-effective. Although the researchers tracked time spent in data collection and analysis (shown in TABLE 4), there was no baseline for comparison. The authors felt that the methodology was reasonably efficient, but suggest that there are opportunities to improve efficiency in image processing, data tabulation, and data calculation. The addition of automated time-lapse photographic technology, while increasing the associated cost, could provide large gains in efficiency, and expand the potential for application.

TABLE 4 Distribution of work effort

Task	Work Effort
Data Collection for 368 bicycle parking spaces	13 hours
Photo Upload, Tagging, and Organization	20 hours
Image Processing, Data Tabulation	25 hours
Calculation and Analysis	25 hours

Recommendations

Despite the limited data collection involved in this study, the authors identified several considerations to facilitate future data collection.

Vantage points and camera setting must be coordinated and tested to provide adequate photo quality for accurate data analysis. Changing light conditions must be considered too.

The time required to analyze photos increases as the number and complexity of racks in the photo increases. The authors found that no more than six “inverted-U” racks should be included in any single photo. Also, other types of racks may demand further consideration.

Locations for analysis should be chosen based on specific research hypotheses; the breadth of locations was sufficient for this feasibility study, but limited the quantity of data related to more precise topics.

Future Applications

The trial study and examples presented in this research suggest that use of the methodology in further study is likely to yield noteworthy results. Detailed results from this type of research also may be generalized and applied to predictive models, or to make adjustments to less comprehensive “snapshot” results.

Furthermore, photographic collection preserves more data than was examined in this study, such as weather conditions, bicycle types, cargo, etc., presenting other opportunities for investigation. The method could be paired with a perception survey to target information such as trip origins and destinations. The use of automated cameras or web-cams could expand and simplify the data collection.

Finally, feedback from city planners, universities, and researchers is needed in order to build consensus on the methods and measures used to investigate bicycle parking.

CONCLUSIONS

In this feasibility study, photographic data was collected for 368 bicycle parking spaces on PSU campus every hour over a period of 12 hours. The methodology developed for the study produced data with potential to offer greater insight into bicyclists' parking behavior than previously available methods. The process employed a simple collection method that required no special training, equipment or software. Measures previously associated with vehicular studies were successfully applied to bicycle parking data and produced results consistent with expectations. The authors believe that these measures represent a toolkit for planners and decision makers to use when evaluating or developing bicycle parking facilities and plans.

The authors believe that time series photography presents opportunities for further study, and provides data suitable for robust statistical analyses. Examples of application and analysis suggest that the data collection and compilation efforts were effective and reasonably efficient, though refinement of the methodology is likely to improve results and efficiency.

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