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ORIGINAL ARTICLE

A case study of bicycle theft on the Washington DC Metrorail system using a Routine Activities and Crime Pattern theory framework

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Abstract This article employs Routine Activities and Crime Pattern theories to explore the factors that lead to increased risk of bike theft, focusing on Washington Metropolitan Transit Authority Metrorail (Metro) property. Utilizing the Metro bike census and other data, we use negative binomial regression analysis to model the relationship between bike thefts and various station- and neighborhood-level risk factors that can either create or close off opportunities for bike thefts. The findings indicate that bike thefts around Metro stations are positively influenced by the number of targets, as measured by the number of bikes per station, and the presence of likely offenders, as measured by the volume of auto-related larcenies. Stations that have greater guardianship, as measured by the number of nearby businesses, are less likely to experience bike theft. The implications of these findings for theory, methodological considerations, and crime prevention are discussed. We suggest that bike racks can be placed in locations with greater informal guardianship, and discuss ways our findings can inform traditional interventions such as bike locking campaigns.

Keywords Bike theft · Routine activities · Guardianship · Transit

Introduction

The increased use of bicycles for commuting purposes in the United States (US) and elsewhere (Pucher and Buehler 2009) represents both a cost-effective response to time-consuming, congested commutes to metropolitan centers as well as a movement toward a greener, more environmentally friendly mode of personal

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transportation.[1] The number of US workers who traveled to work by bicycle increased from about 488,000 in 2000 to about 786,000 during 2008–2012, which was a larger percentage increase than for any other commuting mode tracked by the American Communities Survey (McKenzie 2014). Often such bike commutes are coupled with the use of public transit, with commuters traveling from their homes to commuter rail stations by bike and taking the train to their work destinations. Such is the case of the Washington, DC, area, where the number of bikes parked on Washington Metropolitan Transit Authority Metrorail (WMATA or Metro) property increased from 1,248 to 2,196 between 2007 and 2011. Notably, Metrorail property was also the site of 398 reported bike thefts in 2013; overall bike thefts ranked the second highest crime problem across the rail system in 2015.[2]

Nationwide, while bicycle theft is a low-priority crime with regard to the social harm it causes, it still occurs in significant numbers. In 2013, approximately 190,000 bike thefts were reported to police in the United States, accounting for 3.5% of all reported larceny-thefts (Federal Bureau of Investigation [FBI] 2015). These numbers are a low estimate of the actual incidence of bike theft due to underreporting, with victimization rates estimated at over three times higher than those reported (Integrated Cycle Systems 2006). With the average cost per stolen bike estimated at $435[3] (Moritz 1997), the annual cost of bike theft in the United States alone ranges between $82.6 and $248 million.[4] Moreover, the threat of bike theft and vandalism has been found to pose a "major barrier" to "bicycle-transit integration in the United States" (Replogle 1992, p. 20). Thus, understanding bike theft and the ways in which it can be prevented is particularly important for urban planning projects aimed at increasing bike rider access to public transportation.

With these concerns in mind, this paper examines bike thefts occurring on WMATA property, modeling the degree to which independent variables representing factors that theoretically create or close off opportunities for crime actually do so. Utilizing WMATA's Bicycle Parking Census at Metrorail Stations, crime data, and several other data sources, we set out to answer the following research question: *To what degree do indicators of targets, offenders, guardians, and the broader environmental context capturing routine activities explain station-level differences in bike thefts around rail stations?*

[1] Pucher and Bueler (2009) discuss recent increases in both cycling use and bike-and-ride public transportation infrastructure in the US and Canada. A different study by the same authors (2008) indicates that in other industrialized nations such as the Netherlands, Germany, and Denmark, urban policies to encourage cycling were implemented much earlier on, as early as the mid-1970s.

[2] As indicated to the authors through correspondence with Ronald A. Pavlik Jr., Chief of the Metro Transit Police Department.

[3] A 1997 survey by Moritz put the average cost of a commuter bike at $300 which comes to $435 in 2013 dollars, adjusting for inflation: http://www.bicyclinglife.com/Library/Moritz1.htm.

[4] Based on a range of 190,000 to 570,000 [three times the reported statistic per Integrated Cycle Systems (2006)] bikes stolen annually, and using average $435/stolen bike.

Conceptual framework

Bike theft most commonly occurs outside of homes, on college campuses, and in urban areas, and the present study focuses on the subset of urban bike thefts that occur in the vicinity of transit stations. Offenders committing bike theft likely do so in order to sell stolen bikes or bike parts, or they may steal bikes for their own personal use, known as "joyriding." For this crime type, arrest clearance rates are consistently low, and as a result, victims often do not report thefts because they perceive that there is little police can do to return the bike (Johnson et al. 2008). Bike theft appears to be an opportunistic rather than premeditated crime, as studies at many geographies have consistently found that stolen bikes were either locked poorly or not locked at all (Bryan-Brown and Saville 1997; Challinger 1986; Mercat and Heran 2003; Roe and Olivero 1993). Poorly locked bikes may be susceptible to offenders levering, striking, cutting, or picking the locks, or unbolting the bike components. A bike may also be considered poorly locked when it is locked to an object other than bike racks, such as street signs or trees (known as "flyparking"; see Johnson et al. 2008 for a detailed discussion), allowing potential offenders to lift the locked bike over that object. While many existing interventions seek to address these opportunities directly (e.g., campaigns to encourage proper locking practices), it is worth considering what additional factors contribute to the opportunity to commit bike theft.

Transit stations have been conjectured to pose criminogenic settings for bike theft because owners are likely to leave bikes unattended for long periods during the work day (Johnson et al. 2008). This research on the incidence and correlates of bike theft comports favorably with two environmental criminology theories, Routine Activities theory (Cohen and Felson 1979) and Crime Pattern theory (Brantingham and Brantingham 1981), in that they suggest the convergence of people and targets in space and time can increase or decrease opportunities for bike theft around rail stations.

Routine Activities theory posits that crimes emerge when a likely offender and a suitable target converge in time and space in the absence of a capable guardian. According to this assumption, changes in the routine activities of the overall population can change the interaction of these three elements and therefore affect crime levels. We assume that the contextual factors that affect the routine activities of individuals in and around rail stations will lead to different levels of criminal opportunities for bike thefts around transit stations.

According to the basic tenets of Crime Pattern theory (Brantingham and Brantingham 1981), crime emergence is closely related with the activity and awareness space of likely offenders and suitable targets. Routine activities of likely offenders and suitable targets—and the nodes they visit during these activities (such as work, school, and home)—shape the activity space of these individuals, and eventually their awareness space (Brantingham and Brantingham 1984). Within this awareness space, certain features of an *environmental backcloth*—the elements of an environment such as different land uses, transportation networks, the physical infrastructures of buildings, the economic forces driving a city, or the socioeconomic status of residents—turn into criminogenic settings because of the scope and the volume of the human activity they attract in their immediate vicinity (Brantingham and Brantingham 1981; Brantingham and Brantingham 2008). Referred to as *crime generators* and *crime attractors,* such features become criminogenic at different times with the type (criminal and non-criminal human activities) and level of human activity (changing flows of human activity) at and around these features (Brantingham and Brantingham 1995).

Applied to the present study, Routine Activities theory and Crime Pattern theory suggest that the risk for bike theft will be dynamic across stations of a rail system based on the routine human activities attracted to the stations and to the immediate vicinity of the stations. As Brantingham and Brantingham (1995) noted, transit stations are particularly criminogenic settings because of the large volume of human activity they attract. In this conceptual framework, transit stops are expected to attract criminal behavior because of the unique criminal opportunities they offer with the lack of guardianship at station's off-peak hours. The quality of guardianship at stations is expected to be heavily dependent on both the presence of informal and formal guardians capable of intervening if a crime takes place, such as passengers and other cyclists, or police and transit staff. For instance, robbery of passengers tends to occur in isolated areas of the rail station, as do late-night assaults. In a study of the DC rail stations, La Vigne (1996) found that the only significant predictor of assaults in DC rail station was the absence of an evening attendant. Similarly, with regard to vandalism, the U.K. Department of Transport (1986) found that the areas of the system most affected by graffiti had the least amount of supervision.

Other reasons rail stations can become criminogenic are the lack of familiarity among passengers at transit stations (Piza and Kennedy 2003), poor visibility around stations (Cozens 2003), management and design features of the rail stations (Ceccato 2013; Ceccato, Uittenbogaard, and Bamzar 2013; Ceccato and Uittenbogaard 2014; Cozens 2003; La Vigne 1996; Loukaitou-Sideris et al. 2002; Newton et al. 2014), and the broader environmental characteristics in which the rail stations are situated. This includes accessibility of stations and the potential for human activity around stations, the socioeconomic status of the environment in which each station is housed, and the prevalence of other crimes at stations (Ceccato 2013; Ceccato et al. 2013; Ceccato and Uittenbogaard 2014; Irvin-Erickson and La Vigne 2015; Newton 2014; Newton et al. 2014).

In the present study, the risk for bike thefts at train stations in Washington, DC is modeled by incorporating station- and neighborhood-level indicators of routine activities and guardianship at stations as measured by estimates of human activity in and around stations; activities that can impact the biking environment, such as bike share and bike lockers; the socioeconomic status of the immediate environments in which the stations are situated; and the presence of other crimes at stations. To the best of our knowledge, only two studies have investigated bike theft at the micro-geographical level using a Routine Activities framework similar to that employed in this paper. Wittebrood and Nieuwbeerta's (2000) study examined the relationship between routine activities and repeat victimization, analyzing the repeat incidents of bike thefts among many other repeat crime incidents using national survey data in the Netherlands. They find that urbanization, defined as residing closer to high-crime areas, is a significant predictor of bike thefts. Zhang et al.'s (2007) study of bike thefts in China also employed survey data and found that the lack of home guardianship increases the risk of bike theft at the home. The present study seeks to build on these studies by investigating the relationship between routine activities, informal guardianship, and bike thefts occurring on Washington, DC, Metro rail system properties.

Bike thefts in the DC and transit context

Over the past two decades in the US, overall bicycle use and public transportation use have increased dramatically, creating new opportunities for bicycle-transit integration (Pucher and Buehler 2009). Most large cities in the US have, in turn, initiated new measures to increase bike rider use of transit, including Washington, DC, where WMATA has made increasing bike rider access to rail stations a key component of its strategic plan. WMATA's Metrorail provides service for more than 700,000 customers a day throughout the Washington, DC, area. It is the second busiest rail system in the United States, serving 91 stations in the District of Columbia, Maryland, and Virginia (WMATA 2014) through six subway lines.[5] Bike riders constituted approximately 1% of all riders on Metro trains in 2007, and WMATA's target is to increase this bike rider share to 2% by 2020 and 3.5% by 2030 (WMATA 2010, p. 33). Expanding access to bikers requires a multi-faceted strategy that includes ensuring that there is sufficient bike parking available for the bike rider demand, that bike access is a priority at all levels of Metro's organization, and that commuters are encouraged to ride their bikes. Following this strategy, the number of bikes identified by Metro's Bicycle Parking Census increased from 1,248 to 2,196 between 2007 and 2011.[6] In the same time period, total bike rack capacity for all stations increased from 2963 to 3,544. WMATA has conducted the Bicycle Parking Census in recent years (2007, 2011, 2012, 2013) to estimate the number of bikes parked outside each rail station. These estimates are based on single-point observations during peak hours in summer months, providing a new tool to approximate the number of bikes parked per station annually.

Trends in bike thefts largely mirror this growth in bike rider access to Metrorail, with the 398 bike thefts in 2013 representing a substantial hike of 80% over the 219 bike thefts in 2008 (see Fig. 1). Bike thefts also display seasonal patterns, with more thefts consistently occurring in the second and third quarters of the year, corresponding with the summer months. Similar patterns have been demonstrated in previous work (e.g., Hird and Ruparel 2007).

Total robberies also increased from 2008 to 2013. Although the magnitude of robberies is much higher than that of bike thefts, unlike bike thefts, robberies have traditionally been Metro's most prevalent major crime. In addition to the volume of bike thefts increasing over time, converting bike theft into a rate over the number of total bikes observed for a given year's census shows that this rate has also increased. The figure was 0.11 in 2011, 0.14 in 2012, and 0.17 in 2013. From this, it is evident

[5] During the study period of 2013, there were six lines and 86 stations.

[6] The Bike Census figures are based on one-day observations for each station; they are not annual counts.

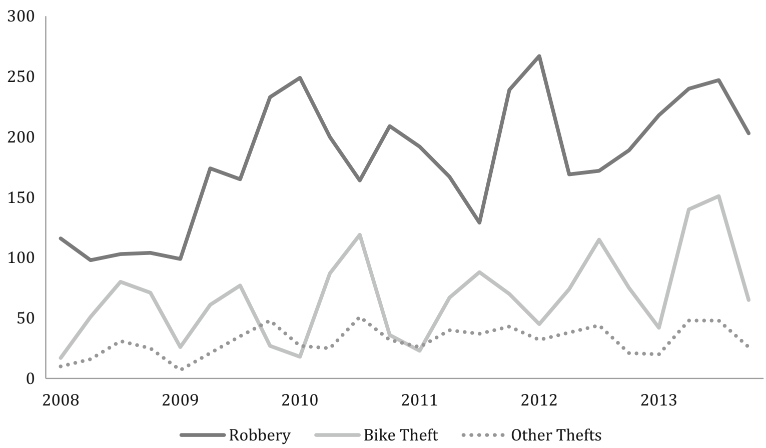

Fig. 1 Frequency of quarterly selected crimes on Metro by year

that there has been a faster rate of growth for thefts than for bikes parked. In all, these upward trends in reported bike thefts and rates call for further investigation.

Analytics

The relationship between bike thefts and a variety of station-level and environment-based characteristics was modeled employing a negative binomial regression, with rail stations ($N = 86$) as the unit of analysis. The dependent variable, the count of bike thefts in 2013 ($N = 398$), is measured as the total number of thefts occurring on WMATA property near rail station entrances, as reported to the Metro Transit Police Department (MTPD). All crime data in the analysis were provided by the MTPD. Close to a quarter of Metro stations (28%) had zero bike thefts in 2013, whereas 57% of the stations had between one and ten bike thefts. This heterogeneous distribution of the bike thefts at Metro stations (skewness = 1.8) and the high number of stations with zero bike theft counts made negative binomial regression analysis the most appropriate modeling approach for this study.

Independent variables

In accordance with this study's conceptual framework, independent variables were grouped under one of the following three categories: (1) measures of suitable targets, (2) measures of informal guardianship, and (3) measures of likely offenders and a crime attracting contextual setting (see Tables 1, 2 for the descriptive statistics for these independent variables). In the regression model, the log of bike theft outcome is given by

$$\mathrm{Log}(Y) = \text{Intercept} + \beta(S) + \beta(G) + \beta(O),$$

Table 1 Descriptive statistics of dichotomous independent variables

	No	Yes
Bike lockers	36	50
Bike share	56	30
Inside City Center	61	25

Table 2 Descriptive statistics for continuous independent variables

	Mean	Median	SD	Min	Max
Bikes parked	26.57	18.5	26.03	0	130
Hourly average ridership	550.16	420.24	419.90	92.15	2081.24
Business establishments[a]	532.49	155	1210.86	0	7052
Failure to Pay (2013)	51.85	27.5	70.60	0	320
Larceny (2012)	1.57	1	1.66	0	7
Robbery (2012)	9.26	5	13.15	0	84
Auto-related larceny (2012)	2.70	0	6.37	0	39
Juvenile crimes (2012)	10.33	4	18.02	0	102
Walkability	3.49	4	1.32	0	5

[a] Number of business establishments within the same block group of the Metro station

where the log of bike theft outcome is predicted with a linear combination of suitable target (S), guardianship (G), and likely offender and crime attracting contextual setting (O) predictor variables (see Fig. 2).

Measures of suitable targets

Bikes parked at rail stations

This independent variable is an estimate of the number of bikes parked outside of each rail station in 2013. These data were acquired from the Bicycle Parking Census at Metro Stations. To conduct this census, WMATA staff count the number of bikes parked within a 150-foot radius of each station during peak months and peak hours (Mid-April through June, from 9:00 a.m. to 3:30 p.m.). Each station has one observation per year, and staff only count bikes on days with good weather. With the exception of bikes locked in the official lockers, all other parked bikes—including those that are locked to an object other than a bike rack—are included in this bike census. A drawback of this variable is that a single-day observation may be unrepresentative of the average number of bikes parked at a station annually. Nonetheless, the census provides the best available measure of bikes parked. Conceptually, this measure of bike volume could have been used as a denominator to measure the dependent variable as a rate. We chose to use volume as an independent variable because the negative binomial regression, a count model, was a better fit for our distribution data. We also believe that employing the bike census

Fig. 2 Operationalization of measures of bike theft at Metro stations

data as a denominator would overstate the relationship between observed bikes parked and reported thefts.

Bike lockers and bike share

The bike locker variable indicates whether a station has bike lockers provided by Metro (0 = No, 1 = Yes). Metro riders can pay $120 to rent a locker for a year. Communication with WMATA staff confirmed that, for each station with lockers, the lockers were first installed in the 1980s. In other words, no station's status for this variable changed during the study period. The bike share variable indicates whether a station has Capital Bikeshare in its immediate vicinity (0 = No, 1 = Yes). Bike-sharing is a system in which stations of rental bikes are provided across the city, enabling users to pick up a bike at one location and use it for a short period before dropping it off at another location. Washington DC's version of this program, Capital Bikeshare, was launched in August 2008 and currently provides over 350 rental locations with more than 3000 total bikes (Capital Bikeshare 2015).

We expect that both the presence of bike lockers and Bikeshare are indicative of a station's biking environment and are thus relevant to the number of thefts that occur there. If the presence of Bikeshare displaced regular bike usage, this could reduce opportunities for theft. The bike stations themselves are very secure, and if a bike is stolen after a Bikeshare member checks it out of the station, that member's credit card is automatically charged $1,000 (Lazo 2014). Bike lockers are one of the key interventions implemented to prevent bike theft. We are interested in assessing, at least partially, the effectiveness of bike lockers as a crime prevention strategy.

However, the variable presents a clear endogeneity issue, as lockers were likely first installed at stations with an identified bike theft problem or high bike traffic. The variable is thus limited as it is difficult to predict its effect or the direction of the effect, but is nonetheless useful for providing an initial understanding of the relationship between lockers and thefts at stations. Furthermore, utilization can be far below capacity and was as low as 41% in 2011 (Perkins 2011). We address these issues and our interpretation of this variable in more depth in the "Discussion" section.

Measures of guardianship

The variables of greatest interest for testing the Routine Activities theory framework are those measuring informal guardianship, or the number of spectators present who are capable of deterring crime. The three variables that we used to measure guardianship are the average number of riders at a Metrorail station (adapted from Clarke et al. 1996), the walkability around the station, and the number of business establishments in the Census block group in which the station is located.

Ridership

Ridership data were provided by WMATA. For each station, we summed the total number of entries and exits to the rail station for the entire year and converted this figure to an hourly average in order to provide meaningful coefficient estimates. Although this method double counts individuals by counting entries and exits, we reasoned this would be the best way to approximate the total volume of individuals at each particular station.

Number of business establishments

The total number of business establishments ($n = 45{,}794$) in the station's block group is intended to measure business activity, and therefore human foot-traffic and informal guardianship, outside of the rail stations. We acquired the data on the number of establishments from the National Establishment Time Series (NETS) dataset.[7] All business types in the dataset were included, which are categorized by the North American Industry Classification System. Due to data availability limitations, we use the number of establishments in 2012.

Walkability

"Walkability" levels around stations is measured with data from *Walkscore.com*, which "measures the walkability of any address based on the distance to nearby places and pedestrian friendliness" (Walkscore 2014). This walkability level is a

[7] NETS is a dataset provided by Wall and Associates Incorporated. They convert Dunn and Bradstreet Corporation's global commercial database into a longitudinal data series that provides annual information on job creation and destruction, sales growth performance, mobility patterns, and other information for establishments in the U.S. economy. For our purposes, we used the address information in the database to estimate the number of business establishments in rail station block groups.

score between 0 and 100 for which lower scores represent car-dependent neighborhoods and high scores represent easily walkable neighborhoods (for our purposes, we converted the scale to values 1–5). We assume that more walkable areas will have more eyes on the street, hence less bike crime.

These three guardianship variables are exploratory, as one could make reasonable hypotheses that increased human activity at and around stations can have a negative effect on the levels of bike thefts through increased guardianship, or a positive effect by concealing the offender. Although the hypothesis that bike thefts should occur during the business day would suggest a negative relationship between human activity and bike theft, Johnson et al. (2008) have hypothesized the opposite relationship, citing the New York Times short film *Bike Thief* as illustrating a case in which human activity can assist the bike theft offender.

Measures of likely offenders and a crime attracting contextual setting

Following Brantingham and Brantingham's notion of crime attractors in an environmental backcloth, we also considered the importance of other neighborhood-level characteristics that can contribute to bike thefts around stations. To reiterate, the backcloth consists of various elements of the environment (e.g., resident socioeconomic status) that may contribute to a criminogenic setting. These elements must be taken into account in conjunction with the other pieces of Crime Pattern theory to have a predictive model. Therefore, in addition to accounting for suitable targets and capable guardians, our model contains four variables to account for environmental factors that may contribute to bike thefts.

Being in the city

The "City" variable indicates if a station is located within a 2.5 mile radius of the Metro Center rail station (0 = No, 1 = Yes), located in the middle of DC's business district. This variable is consistent with the geographic concept of distance decay—that concentrations of human geography decline with greater distance from the center of central business districts (see Rattner and Portnov 2007). We view City as an exploratory variable, as one could make a reasonable assumption that crime, and therefore bike thefts, is higher in areas with higher human flows. Conversely, we might expect a higher number of bike thefts at remote suburban geographies due to greater availability of unattended bikes or less guardianship.

Socioeconomic status

Our second variable in this category, "Socioeconomic Status (SES)," measures the SES level in the block group in which each station is located, using a factor variable produced with principal component analysis of five common indicators of socioeconomic status: the percentage of white population, the percentage of residents with a bachelor's degree or higher, the percentage of residents owning their homes, the percentage employed, and the median household income (eigenvalue = 3.30). The data for these variables were extracted from the 2008–2012

American Community Survey (ACS) estimates. As is traditionally the case with other crime types (Shaw and McKay 1942; Sampson and Groves 1989; Sampson et al. 1997), we would expect low SES level in the immediate vicinity of the Metro stations to correspond with higher bike thefts.

Other crimes

Routine Activities theory stipulates that in order for a crime to occur, a likely offender needs to be present. Furthermore, Crime Pattern theory suggests that certain places that provide well-known criminal opportunities will be crime attractors for other crimes. It is difficult to isolate a measure for potential offenders (any variable of crime incidents will also be indicative of the presence of a target and the absence of a capable guardian), but the inclusion of other crime variables into our regression model is designed to investigate how bike thefts interact with the rest of the crime environment. These variables are robberies occurring in rail stations, other thefts occurring in rail stations, juvenile crimes, and auto-related thefts (including both theft from automobiles and thefts of automobile parts) occurring in Metro parking facilities. These variables serve two functions. All of them share characteristics with bike thefts, and we may expect them to serve as a control for broad crime fluctuations. The relationship between auto-related thefts and bike thefts is of particular interest because we would hypothesize that these thefts are most analogous to bike thefts in their occurrence. The other function of these variables is that each one is set for 2012 instead of 2013 to control for unmeasured station characteristics that may change overall crime levels from year to year. Based on our theoretical framework, a measure of vandalism events would have been a logical variable to include, but these incidents are very rare on the DC Metro.

Fare evasion

The number of fare evasions occurring at a station may measure both the presence of likely offenders as well as the presence of capable guardians. Reporting on the New York City subway, an article by Finder (1991) and a study in greater London (Cubic Transportation Systems 2005) have found that efforts to reduce fare evasion correspond with reductions in other serious crimes, suggesting that the offenders who evade fares often also commit more serious crimes. Fare evasion is one of the most common subway crimes,[8] so it may be a good indicator for the presence of offenders who could commit other crimes, assuming the opportunities for those crimes arise. This logic would suggest that we use fare evasion incidents to measure the number of potential offenders. On the other hand, data on fare evaders are generated by those incidents that come to the attention of staff or law enforcement, suggesting that this variable might also serve as a proxy for guardianship. We therefore include fare evasion as an exploratory variable.

[8] For instance, in 2013 on all DC rail stations, combined reported fare evasions and fare evasion warnings totaled to 4459, making it the most frequent crime among all Part I and Part II crimes. The next most frequent crime was robbery “snatches,” totaling to 547.

Results

In 2013, 398 bike thefts were reported to the MTPD. The average number of bike thefts at a station was 4.63 (standard deviation [SD] = 6.15, minimum [min] = 0, maximum [max] = 28). In accordance with the conceptual framework employed in this research inquiry, we would hypothesize that bike thefts primarily occur during work days when riders leave them unattended for long periods of time. Descriptive analysis of bike thefts by day of week supports that hypothesis, demonstrating that most bike thefts at DC rail stations are a weekday phenomenon. When averaging for the number of weekdays and weekend days in a week, bike thefts are 2.7 times more likely to occur on weekdays. Unfortunately, the data do not allow us to say with certainty the time of day that bike thefts occur, but only the time that the theft was reported to an MTPD officer. However, reports of bike thefts to the police peak between 6:00 p.m. and 7:00 p.m. indicating that the thefts are discovered when commuters return by rail to their home stations at the end of the work day.[9]

As illustrated in Fig. 3, out of all the stations included in the analysis, only five stations—College Park-University of Maryland (College Park-U of MD), East Falls Church, Twinbrook, Vienna-George Mason University (Vienna-GMU), and West Falls Church stations—had bike thefts that were more than two standard deviations from the mean. The station with the most thefts, Vienna-GMU, had a total of 28 bike thefts in 2013. Furthermore, the stations serving the suburbs of the Metro coverage area, especially the orange line segment serving the Virginia suburbs (including the Vienna-GMU station) and the green-yellow line segment serving the suburbs of Maryland (including the College Park-U of MD station) experienced a higher number of bike thefts in comparison to other lines serving Washington, DC, and the suburbs of Virginia and Maryland.

Although our model seeks to assess the interaction between bike thefts and all of the independent variables, one relationship of particular interest to understanding the model in context is that between bike thefts and bikes parked. The number of bikes parked, our primary variable to measure the suitable targets in the immediate vicinity of the stations, was a positive correlate of bike thefts (See Fig. 4). As shown in Table 2, the average number of bikes parked at stations was 26.5 (SD = 26, min = 0, max = 130). East Falls Church, College Park-U of MD, and Vienna-GMU stations, which were among the stations with the highest count of bike thefts, were also the stations which had the highest counts of parked bikes (parked bike counts of 104, 66, and 90, respectively). As one might expect, we also observed exceptions to the expectation that the stations with the most bikes parked will have

[9] Research has demonstrated the difficulty of predicting the time of a bike theft, given a range of time it was left unattended. Ashby and Bowers (2012) analyze 303 bike thefts occurring at railway stations in Great Britain in which the offense was captured on a CCTV security camera, and the real offense time could therefore be determined. Using the time range that was reported to the police for each incident (starting with the time the victim left the bike unattended, and ending when they returned to the location), the authors demonstrate that using the start time, mid-point, or end time of the range to predict the actual time of theft results in poor predictions.

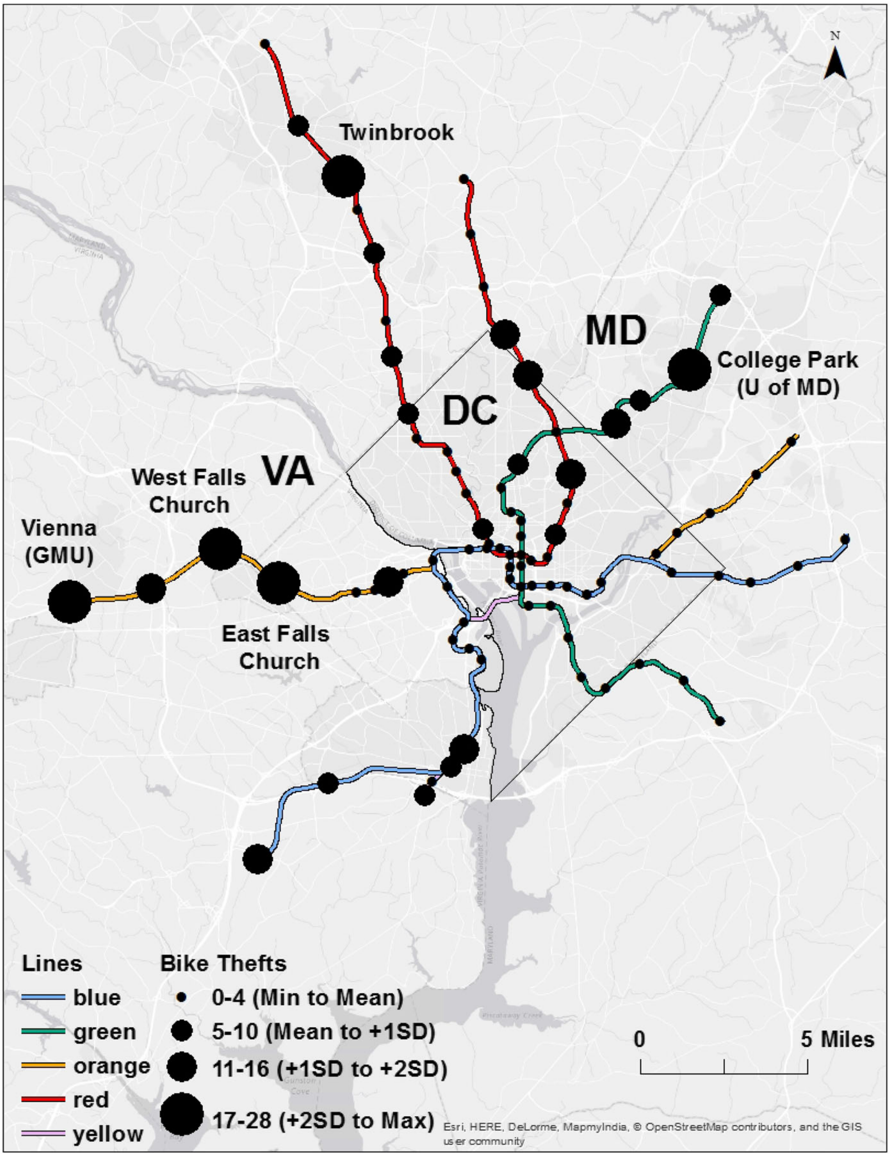

Fig. 3 Bike theft counts on Metro in 2013

the most bike thefts. Union Station and Takoma, which had parked bike counts more than two standard deviations from the mean number of parked bikes, had 0 and 12 bike thefts in 2013, respectively.

Table 3 illustrates the results from the regression analysis. Consistent with the results from our descriptive analysis, the results support a positive and significant relationship between bikes parked and bike thefts controlling for the effect of other independent variables ($b = 0.021$, $p < 0.001$). The regression analysis results also

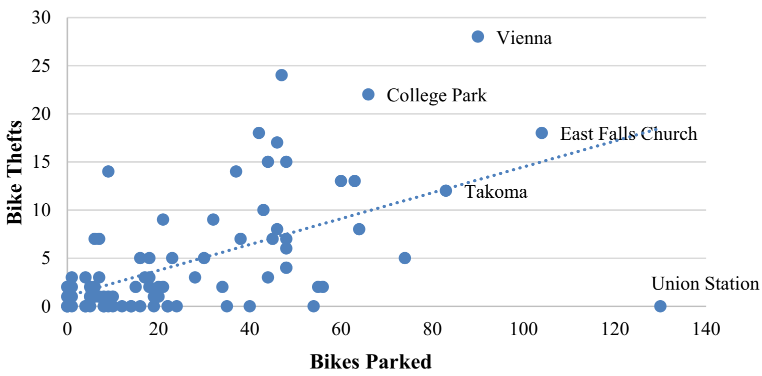

Fig. 4 A two-way plot of the number of bikes parked and bike thefts on Metro in 2013

Table 3 Results of negative binomial regression analysis for 2013 bike thefts

	Coefficient	SE
Measures of suitable targets		
Bikes parked	0.0211**	0.0050
Bike lockers (0 = No, 1 = Yes)	1.3170**	0.2942
Bike share (0 = No, 1 = Yes)	0.3390	0.3775
Measures of informal guardianship		
Hourly average ridership	−0.0001	0.0004
Business establishments	−0.0005*	0.0003
Walkability	0.1503	0.0997
Measures of likely offenders and a crime attracting contextual setting		
City (0 = No, 1 = Yes)	−1.0625*	0.4322
SES	−0.0488	0.1460
Larceny	−0.0845	0.0801
Robbery	−0.0039	0.0151
Fare evasion	−0.0025	0.0021
Auto-related larceny	0.0315***	0.0185
Juvenile crimes	−0.0010	0.0141
Constant	$R^2 = 0.186$	

* Significant at ≤ 0.05, p level

** Significant at ≤ 0.001, p level

*** Significant at ≤ 0.10, p level

found that the presence of bike lockers, another proxy measure for suitable targets, was a significant predictor of bike thefts around Metro stations ($b = 1.323$, $p < 0.001$).

Regarding the relationship between guardianship and bike thefts, one of two variables serving as a proxy for level of human activity around stations was a significant predictor of bike theft, and this was the number of business establishments within the block group of a station. In the block groups with a smaller number of business establishments (and therefore less human activity), there were a significantly higher number of bike thefts ($b = -0.001$, $p < 0.05$). While the coefficient seems very small, it is important to note that the number of businesses around Metro stations is quite high, with a mean of 532 (see Table 2).

Lastly, regarding the relationship among likely offenders, a crime attracting contextual setting, and bike theft outcomes, regression analysis results show that the log of expected count of bike thefts around stations was higher if the station was outside of the city ($b = -1.062$, $p < 0.05$) and if there was a higher count of auto-related larcenies in the parking lots around the stations ($b = 0.032$, $p < 0.1$). These results support the hypothesis that stations in the suburbs and outside of the city center can attract more likely offenders due to bikes being left unattended for long periods of time by rush hour commuters.

It is also worthwhile to compare these results to other studies employing similar methodologies. The findings in the present study correspond with those reported in Zhang et al.'s (2007) study of bike thefts in China with regard to guardianship variables, as that study found that the number of adult residents in a household was a significant predictor of fewer bike thefts. In contrast to this study, Zhang et al. (2007) found a significant and positive relationship between high-poverty neighborhoods and bike thefts. They also found no significant relationship between the number of household bikes and bike thefts, their measure of suitable targets, while the present study found a strong and positive relationship between bikes parked and bike thefts. Additionally, Wittebrood and Nieuwbeerta (2000) found that proximity of residence to urban, high-crime areas is a significant predictor of bike thefts, whereas this study found a significant relationship in the opposite direction.

Discussion

WMATA's yearly bike census provided us with a valuable tool to estimate the number of bikes present at each Metrorail station. Using this and other cross-domain data, this research inquiry was designed to understand the degree to which bike thefts at rail stations could be explained by a conceptual framework informed by the Routine Activities theory and Crime Pattern theory. We hypothesized that bike thefts at rail stations should occur when individuals leave their bikes unattended for long periods during the workday, and analysis results showed that bike thefts are indeed a business-week phenomenon, suggesting that commuters are those that most commonly fall victim to bike thefts on Metro property. While the precise time of theft is unknown, peak reports to police at the end of the work day are consistent with the hypothesis that they occur while bike riders are at work.

Among the Routine Activities theory variables tested, those measuring guardianship are particularly important to our hypothesis, as the presence of bystanders should be a deterrent to bike theft. The regression results provided some evidence that proxies for human activity around stations can be a valuable guardianship measure in explaining where bike thefts do and do not occur, in that the business establishments variable was significant in the negative direction (as the number of establishments increases, bike thefts decrease). However, the ridership variable was not significant (see Table 3). This could be because bike thefts occur outside of stations, and business establishments are a better measure than ridership of the total activity occurring in close proximity to the actual theft location.[10]

Regarding the second tenet of Routine Activities theory, the presence of suitable targets, we found evidence that the increased presence of bikes around stations provided better opportunities for bike theft, even if the stations had bike lockers. This is not entirely surprising, as it is not possible to observe bike thefts absent the presence of bikes. However, the moderately strong correlation between bikes parked and bike thefts is illuminating: if one station has ten bikes parked and another has twenty, it is not automatically intuitive that a bike theft should occur at the latter station and not the former. Yet, the analysis results found that more bikes parked predicts more bike thefts. Research indicates that most stolen bikes are those that are poorly secured and thus easier to steal (Bryan-Brown and Saville 1997; Challinger 1986; Mercat and Heran 2003; Roe and Olivero 1993). Perhaps, stations with more bikes also have a higher share of poorly locked bikes, resulting in more thefts over time. Evidence for this can be demonstrated in Sidebottom et al. (2009), in which bicycle parking sites are observed before and after an intervention to improve locking practices, and roughly 60% of pre-treatment bikes are locked poorly. By their system, a bike is locked "poorly" if only the wheel, only the frame, or neither is locked to a rack; it is "ok" if one wheel and the frame is locked; and it is "good" if both wheels and the frame are locked. It also may be the case that a station with more bikes has more opportunities for an offender to find one that is suitable to his/her needs, whether those needs are personal use or for resale.

Bike lockers, which are the primary intervention intended to prevent bike theft at rail stations, were also a positive and significant correlate of bike thefts around stations (lockers at stations correspond with more thefts). We must stress that, because our model is not a pre-test–post-test design, it does not tell us about the impact of installing lockers at stations. What it does tell is if bike lockers are a predictor of where thefts occur. This likely means that lockers were installed at stations that historically had the most bike thefts or bikes parked. Indeed, across all five years we have data, the total number of thefts at stations with lockers dramatically exceeds that number at stations without lockers. The same pattern holds for bikes parked (see Figs. 5, 6).

Several variables—fare evasion, SES, other crimes, and the city variable—were used to explore the effect of the presence of likely offenders and a crime attracting contextual setting on bike theft incidents. In other words, we sought to account both for the number of offenders, as well as characteristics that would be considered part of the environmental backcloth in Crime Pattern theory. The fare evasion variable served as a proxy for likely juvenile offenders for bike theft but was not a significant predictor of bike thefts. This result makes it difficult to comment on whether the fare evasion variable may be a poor measure of actual fare evasion and the presence of

[10] The Pearson correlation between these two variables, business establishments and hourly average ridership, was 0.54 indicating that these two variables have a moderate correlation, however not to the extent to suggest that multicollinearity might be a problem.

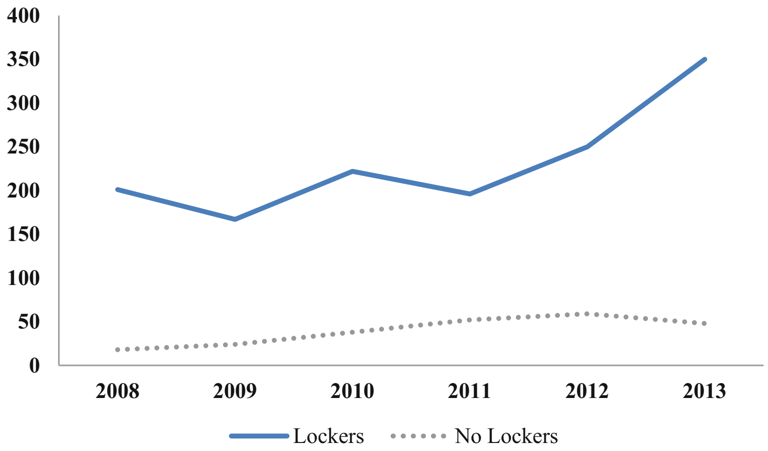

Fig. 5 A comparison of bike theft counts at stations with and without lockers (2008–2013)

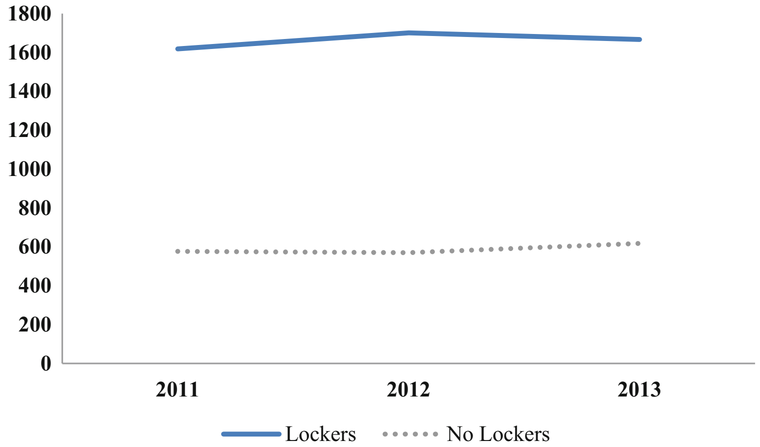

Fig. 6 A comparison of observed bikes parked at stations with and without lockers (2011–2013)

likely offenders, or if there is simply no relationship between fare evasions and bike thefts. The SES variable was a measure for environmental context and was not significant. This is notable because SES is often used as a proxy for measuring social disorganization.

The additional crime variables and city variable are worth discussing together, suggesting that bike theft, auto theft, and theft from auto share a unique opportunity structure resulting from low levels of activity at stations and owners' prolonged detachment from their property. Auto-related theft in parking lots was a significant and positive predictor of bike thefts around stations, providing evidence for the similarity. The city variable was a significant negative predictor of bike thefts, with bike thefts occurring more often at stations further from the city. This coefficient counters what one would expect from the distance decay hypothesis, and supports the hypothesis that stations in the suburbs and outside of the city center can attract more likely offenders due to bikes being left unattended for long periods of time by rush hour commuters. La Vigne and Lowry (2011) found a similar phenomenon with regard to car-related crimes on DC Metro property, a finding that is consistent with other car crime studies (Clarke 2002; Clarke and Mayhew 1998).

There may also be alternative reasons that the opportunity structure for bike thefts would lead to results that seem to counter the distance decay hypothesis. One can argue that the friction of distance decay might be less strong for bike theft due to the ease of accessing and leaving the vicinity. We may additionally consider the crime opportunity structure in conjunction with the potential reasons that offenders steal bikes. Research conducted in different jurisdictions has demonstrated different measures of the percentage of bikes that are stolen either for resale or for personal use (Johnson et al. 2008). It is possible that locations further from the city center provide easier opportunities for resale. Research on resale markets, though, has not looked specifically at locations of resales within a city and cannot corroborate this finding (e.g., Stevenson and Forsythe 1998).

Conclusion

This study contributes to the theoretical literature on bike thefts, Routine Activities theory, Crime Pattern theory, and environmental criminology in several ways. While there is already a significant body of work showing the merits of Routine Activities theory and Crime Pattern theory, our model further showcases the explanatory power of the variables informed by these theories in explaining the very specific opportunity structure for different crime types. Overall, the results suggest that prevention resources are best allocated to those stations that have high volumes of suitable targets (bikes parked), other indicators of criminal activity (presence of likely offenders), and few nearby businesses (absence of capable guardians).

Future work could investigate the theoretical implications of this study through experiments or qualitative observations. The findings surrounding informal guardianship raise the question of whether the mere presence of bystanders is sufficient to deter crime or if deterrence is born from those bystanders who actually intervene in crimes in progress. From a broader environmental approach, our results also raise new hypotheses about the mechanics of how bike thefts occur. For instance, we suggest that a reason for the correlation between bikes parked and bike thefts could be that more bikes parked also means that more bikes are locked poorly. Bike thefts also appear to occur under similar conditions as auto-related thefts.

The study also raises methodological considerations for future work. The use of a bike census offers an advantage over survey data because it creates a measure of parked bikes that were actually observed in a specific geographic location. This allows for an analysis of thefts in a unique geographic space, such as the vicinity of Metro stations, whereas survey data of bike ownership could only be used to analyze thefts at the household level. This method may overestimate the pool of available bikes, as the bike census is conducted during peak summer months, but we assume that it is still a good measure of relative bikes parked at each station. Research can also further dissect the use of ridership and business establishments as the measures for station activity, particularly if one is advantageous over the other in particular circumstances, or determine if reported fare evasion incidents is an accurate proxy for formal guardianship. Future iterations of the bike census in Washington, DC can employ a methodology similar to the methodology in Sidebottom et al.'s (2009) study to determine the adequacy of locking practices.

With regard to the study findings and their implications for crime prevention and practice, the significance of informal guardianship suggests that station planners may find ways to increase the visibility of official bike racks so that bikes are parked in locations with more potential guardians. Placing bike rental or repair shops near station entrances could also provide additional guardianship (Johnson et al. 2008). It is likely, though, that traditional interventions would be more direct and cost effective. Research has found that many of these interventions show promise. Campaigns encouraging individuals to lock their bikes or the implementation of different types of bike stands have been shown to improve locking practices (although studies have not evaluated the ultimate impact on thefts), and traditional bike registration programs seem to be particularly advantageous in ensuring that bikes are returned to their owners (Sidebottom et al. 2009). At a higher level of intervention, the University of Minnesota Police Department implemented a policy of fining owners who did not park their bikes to official furniture, and suggested that the intervention reduced thefts by 57% over a two-year period (Cook 2006). Still, the study findings could inform such interventions. For instance, if these findings add to the evidence that poor locking practices lead to the most theft, it would suggest that bike locking campaigns are an appropriate intervention.

A limitation of the model is that it did not seek to investigate many of the specific behaviors that would inform the design of the above interventions, such as bike locking practices or the likelihood of intervention by informal guardians. Similarly, there were no data to measure official police presence. However, correspondence with MTPD Chief Ronald Pavlik indicated that the department increased its focus on this issue following 2013, which coincided with a decrease in overall thefts. Recent interventions implemented by MTPD have included bait bikes, free bike registration, free lock exchanges, and expensive bike hotels, although it must be noted that bike thefts continued to be the second highest crime problem for MTPD in 2015. It would be worthwhile for researchers to investigate a variety of interventions, including those that do not require increased policing efforts, because police forces may not always be willing to allocate officer time specifically to bike theft.

Overall, the findings from this study provide evidence that there are various station- and neighborhood-level target, offender, and guardianship factors that are related with a high number of bike theft incidents. We expect that the findings will contribute to the field of environmental criminology and expand in particular our understanding of transit crimes and bike theft.

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