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A Spatio-temporal Analysis of Crime at Washington, DC Metro Rail: Stations' Crime-generating and Crime-attracting Characteristics as Transportation Nodes and Places

Yasemin Irvin-Erickson* and Nancy La Vigne

Abstract

Transit stations are acknowledged as particularly criminogenic settings. Transit stations may serve as crime "generators," breeding crime because they bring together large volumes of people at particular geographies and times. They may also serve as crime "attractors," providing well-known opportunities for crimes. This paper explores the node and place characteristics that can transform Washington DC, Metro stations to generators and attractors of different crimes at different times of the day. The crime-generating and crime-attracting characteristics of stations are modeled with Negative Binomial Regression analysis. To reflect the temporal trends in crime, crime counts are stratified into three temporal groups: peak hours, off-peak day hours, and off-peak night hours. The findings from this study not only suggest that stations assume different nodal and place-based crime-generating and crime-attracting characteristics, but also these roles vary for different crimes and different times. The level of activity and accessibility of a station, the level of crime at a station, and the connectedness of a station to other stations are consistent indicators of high crime rate ratios. Different characteristics of a station—such as being a remote station or belonging to a high or low socioeconomic status block group—are significant correlates for particular crime outcomes such as disorderly conduct, robbery, and larceny.

Keywords: Transit; Rail; Node; Place; Temporal; Crime; Station

Background

It is a long established criminological fact that situational factors related to place and time play a key role in creating opportunities for crime. Crimes require the convergence of the victim and offender in place and time. Environmental crime studies have been successful in introducing the importance of micro places in criminological research. However, studies based on place-based indicators provide an incomplete picture of crime emergence. In context-based analysis of crime risk, studies of the relationship between environmental risk features and crime assume a temporally uniform criminogenic influence of land use features. Despite the stationary nature of landscape features, criminogenic influence of land uses will not be uniform across time because human activities occur at specific locations for a limited duration. Transit stations, based on the rhythms of human activity inside and outside of the stations, the characteristics of the stations, and the broader environment in which they are situated, can serve as particularly criminogenic settings (Ceccato 2013; Ceccato and Uittenbogaard 2014, Newton 2014).

Transit stations may serve as crime "generators," breeding crime because they bring together large volumes of people at particular geographies and times. They may also serve as crime "attractors," providing well-known opportunities for crimes. It is conceivable that even the same transit hub could serve multiple roles—being both an attractor and a generator— as its use, and that of the surrounding area, changes over time (Block and Davis 1996;

* Correspondence: YIrviner@urban.org
Justice Policy Center, the Urban Institute, 2100 M Street, NW 20037, USA

Ceccato 2013; Liggett et al. 2003; Newton 2014; Smith and Cornish 2006).

This paper explores the node and place characteristics that can transform particular rail stations to generators and attractors of different crimes at different times of the day. Several of the indicators used to operationalize the nodal and place-based crime-generating and crime-attracting characteristics of stations are adapted from Bertolini's (1996) node-place model.

According to Bertolini (1999), in the contemporary city, transit hubs are one of the few places that bring together many people from heterogeneous backgrounds physically together. According to the author, accessibility of a place is not just a feature of a transportation node ('how many destinations, within which time and with which ease can be reached from an area?'), but also of a place of activities ('how many, and how diverse are the activities that can be performed in an area?'). (p.201)

Nodes refer to central places where people go to or gather in their routine activities. Nodes have been a focus of environmental criminology for a long time, especially in the study of daily rhythms of human activities in Crime Pattern Theory (Brantingham and Brantingham 1981) and Routine Activities Theory (Cohen and Felson 1979). Bertolini's node and place model in urban planning, however, was first brought to the attention of the researchers of crime at and around transits stations by Ceccato (2013), Ceccato et al. (2013), and Ceccato and Uittenbogaard (2014). In their studies of the crime and perceived safety in and around underground stations, the authors looked at crime patterns at and around stations at different times of the day, different days, and different seasons. The authors used several indicators related to a station's platform, transition area, lobby, exit-entrance, and immediate vicinity to assess the relationship between different node and place characteristics of stations and various crime outcomes. These studies provided evidence that "security in underground stations is a function of not only of the local conditions, but also the surroundings in which these stations are located" (Ceccato et al. 2013, p. 52). In another study of pick-pocketing in and around mass transit stations, Newton et al. (2014) also assessed the characteristics of stations and the environments of the stations that increased or decreased the risk for pick-pocketing. Adapting several of the measures used in Chorus and Bertolini's (2011) study of the transit hubs, this study expands on the results of the studies of Ceccato (2013), Ceccato et al. (2013), and Newton et al. (2014) by including different measures to quantify the level of activity and the station characteristics. Furthermore, we create a typology for the crime-attracting and crime-generating nodal and place based characteristics of metro stations at different times. This approach—which builds upon the work of Bertolini (1996; 1999), Brantingham and Brantingham (1995), Ceccato (2013), Ceccato et al. (2013), Ceccato and Uittenbogaard (2014), Chorus and Bertolini (2011), and Newton et al. (2014)—allows us to quantify and measure particular groups of nodal and place-based crime-attracting and crime-generating characteristics of stations that relate to different crimes at different times of the day. The argument, therefore, operationalizes what the crime-generating and crime-attracting characteristics of stations are, allowing us to test which of these environmental backcloth characteristics are related to different crimes at different times. This study is distinguished from other studies of crime at and around stations because it attempts to quantify and measure how a station becomes a crime attractor or crime generator, or both, based on several static and dynamic nodal and place-based station characteristics.

This paper tests the hypothesis that a transit hub's role in crime production can vary based on several place-based and nodal characteristics of the stations, and temporal variations, which can change the environmental context based on who is in and around the station at any given time. We test this hypothesis by examining robbery, larceny, aggravated assault, and disorderly conduct at Washington, DC Metrorail (Metro) transit stations. Analyses are conducted to include the crime-generating and crime-attracting node and place characteristics for aforementioned crime types at different times of the day.

The nodal crime-generating and crime-attracting characteristics of stations are explored by examining: 1) the connectedness of particular stations to the rest of the transit system; and 2) the remoteness of the station from the central business district. The place-based crime-generating and crime-attracting characteristics of stations are explored by examining: 1) the accessibility of stations and the potential for human activity around stations; 2) the socioeconomic status of the environment in which each station is housed; and 3) the prevalence of other crimes at stations.

In this study, the physical attributes of the Metro stations are not taken into consideration because past research showed that with Metro's uniformity in design and maintenance, "design and maintenance variables would yield little in the way of statistically significant results" (La Vigne 1996b, p. 164).

The study addresses the following research question: "To what degree do crime counts at Metro stations vary according to the nodal and place-based crime-generating and crime-attracting characteristics of the stations?" The following sub-research questions are implicit in the overarching research question:

- Do variations indicate the role of some stations as nodal generators of crime, nodal attractors of crime, place-based generators of crime, place-

based attractors of crime, or a combination of two or more?
- Do these roles change for different crimes and different times of the day?

Theoretical and Conceptual Framework

The relationship between spatial context and crime was incorporated into contemporary criminology through the socioecological explanation of criminality. The forerunner of this approach was Park and Burgess's examination of how urban environments affect human criminal behavior (Burgess 1925). Park and Burgess's notions of natural areas and concentric zones inspired the members of the Chicago School to perform field research on the effects of urban environments on crime and disorder. Shaw and McKay (1942) pointed to the pathological criminality of certain neighborhoods and attributed this criminality to the endemic social disorganization rather than the criminal tendency of residents in these neighborhoods. According to the Chicago School, "one cannot understand social life without understanding the arrangements of particular social actors in particular social times and places" (Abbott 1997, p. 1152). Environmental criminology theories following the Chicago School emphasized that criminal behavior can be understood by understanding how people react to their physical environments (Savage and Vila 2003). For instance according to Routine Activities Theory

> Strong variations in specific predatory crime rates from hour to hour, day to day, and month to month are reported often … and these variations appear to correspond to the various tempos of the related legitimate activities upon which they feed. (Cohen and Felson 1979, p. 592)

Similarly, according to Crime Pattern Theory, criminal decisions are affected by the environmental backcloth—the elements of an environment such as land uses, design features, physical infrastructure of buildings, transit hubs—that can influence individuals' criminal behaviors (Brantingham and Brantingham 1981). According to Brantingham and Brantingham (1995), the way people conceptualize space and the way the space restraints human activity are important considerations for understanding crime patterns. Brantingham and Brantingham (1995) differentiated between *crime generators* and *crime attractors* in an environmental backcloth. Crime generators are activity nodes that provide greater opportunities for crimes because of the high number of people that use these nodes, whereas crime attractors are activity nodes that attract offenders because of their well-known criminal opportunities (Brantingham and Brantingham 1995).

Another theoretical framework outside of the discipline of criminology, the Time Geography framework, also acknowledges that human activities are interconnected on temporal and spatial dimensions (Hägerstrand 1970). Time Geography mainly focuses on interrelationships between activities in time and space, and how these interrelationships impose constraints on human behavior (Miller 2004, 2005). One collection of constraints that places can exert on human activities is known as *coupling constraints*, which dictate "where, when, and for how long, an individual has to join with others to produce, transact or consume" (Miller 2005, p. 221). Although individuals can plan where and when flexible activities occur, dependent on the locations and operating hours of the venues offering these activities, even flexible activities might be restricted in time and space (Miller, 2004). Based on the restrictions that settings put on the movement patterns of offenders and targets, different places can become risky places for crimes at different times. The notions of the time geography framework in this study are used to stratify crimes at rail to different daily and hourly temporal groups dictated by the daily and hourly rhythms of human activities.

When applied to transit stations collectively, these theories suggest that the crime trends at transit stations can vary both temporally and in content. These variations are dependent on the crime-generating and crime-attracting characteristics a station assumes based on the rhythmic and repeating patterns of human activity. The current literature on crimes at and around the stations also supports this conclusion. For instance, as mentioned earlier recent studies of crime in and around subway stations concluded that opportunities for different crimes are related to the immediate environment in which the stations were housed and the city context (Ceccato, 2013; Newton et al. 2014). Ceccato (2013) also found that the rates of crime events changed temporally, "some stations were crime-specialized," and end of the line stations had higher rates of crime than stations in the city areas (p.42). Other studies on transit stations in the US and UK also showed that crimes at transit stations were related to the land use and socioeconomic status around stations (Block and Davis 1996; La Vigne 1996a; Liggett et al. 2003; Loukaitou-Sideris 1999; Loukaitou-Sideris et al. 2002; Newton and Bowers 2007; Newton et al. 2014).

We adapt several indicators from the node-place model of Chorus and Bertolini (2011) to operationalize the crime-generating and crime-attracting characteristics of Metro stations. The node-place model of Bertolini (1996) was developed to identify the transit and land use factors that shape the development of station areas. In the Chorus and Bertolini (2011) study, number of train stations, type of train connections, proximity to central business district, and number of bus lines from a station are used to identify the node value of a station. The place value of a station is defined by the population, economic clusters, and degree of multifunctionality around the stations. In our study, borrowing from the Chorus and Bertolini (2011) indicators and based on key studies informing our theoretical framework (i.e., Ceccato 2013; Ceccato et al. 2013; Newton et al. 2014), we create two node variables and three place variables to measure the crime-generating and crime-attracting characteristics of Metro stations.

The first node variable, “Connectedness,” measures the connectedness of each station to the rest of the transit system. The better a station is connected to the rest of the transit system, the more potential victims and targets it will converge spatiotemporally. Thus, this nodal characteristic is assumed to be a crime-generating characteristic. The second node variable, “Remoteness,” measures the remoteness of the station from the center of the transit system. This nodal characteristic is assumed to be a crime-attracting characteristic since remote stations have been shown to have higher rates of crimes and also they were suggested to provide unique opportunities for crimes such as disorderly conduct, graffiti, and vandalism (Ceccato, 2013; Ceccato et al. 2013). These types of crimes are more likely to attract offenders who are seeking targets that lack guardianship.

The first place variable, “Accessibility and Activity Level,” measures the ease of access and the potential level of activity around the stations. Easily accessible multifunctional stations are assumed to provide more opportunities for human activity. Therefore, this place characteristic is assumed to be a crime-generating characteristic. The second place variable, “Socioeconomic Status (SES),” measures the SES level in the immediate geography in which the stations are housed. In criminology, SES is commonly used as a proxy for social disorganization (Hart and Waller 2013). Since places with high social disorganization are theorized to provide unique opportunities for different crime outcomes (Sampson and Groves 1989), this place characteristic is assumed to be a crime-attracting characteristic. Lastly, the place variable, “Other Crimes,” measures the prevalence of specific crimes at the stations. Prevalence of other crimes that can thrive on the same opportunities for a particular crime at stations is assumed to be an indicator of better opportunities for that crime. So “other crimes” is used as an indicator of a station’s status as a crime attractor. The operationalization of these node and place variables is explained in detail in the Methods section.

Method

Study setting: Washington DC, Metro

The study setting is the Washington DC, Metro. Metro 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 District of Columbia, Maryland, and Virginia (WMATA 2014). Metro has six lines: blue, green, red, orange, silver, and yellow lines (see Fig. 1). In this study, 86 of the 91 stations were included in the analysis. Five silver line stations which were opened in 2014 were excluded.

Modeling

Negative Binomial Regression was used to model the dependent variables as a function of nodal and place-based crime-generating and crime-attracting characteristics of stations.

Dependent variable

The dependent variables of this study are the counts of Part 1 robbery ($N = 421$), larceny ($N = 234$), aggravated assault ($N = 34$) and disorderly conduct ($N = 169$) incidents at Metro rail stations in 2008. These counts only include the crimes at the metro rail excluding the crimes that occurred on the other WMATA property or the parking lots adjacent to the stations. This data were acquired from Metro Transit Police Department (MTPD). The dependent variables were assigned to three different time groups to reflect the counts of the dependent variables during the peak and non-peak hours of the Metro system. “Peak hours” are 4.30 a.m. - 9 a.m. and 3 p.m. - 7 p.m. “Non-peak day hours” are 9 a.m. - 3 p.m. “Non-peak night hours” are 7 p.m. - 4.30 a.m. These temporal groups made intuitive sense for the Metro study setting and the operating hours of the system. Metro operates seven days a week, opening at 5 a.m. on weekdays and at 7 a.m. on weekends, and closing at 12 a.m. Sunday-Thursday and at 3 a.m. on Friday-Saturday (WMATA 2014).

Independent variables

Connectedness This represents the connectedness of each station to the rest of the transit system. A factor variable was produced with an exploratory factor analysis of two dichotomous variables in STATA using the polychoric and matrix commands (rho = 0.39, eigenvalue = 0.52). The first binary variable, “Interchange,” indicated if the station was an interchange station providing cross-platform interchange between lines (Yes = 1, No = 0). The second binary variable, “Connection,” indicated if the station provided connections to any other rail transit systems (i.e., Amtrak, Virginia Railway Express, Maryland Area Regional Commuter) (Yes = 1, No = 0). Connectedness is a node characteristic of a transit system and is expected to serve as a crime-generating characteristic because of the dense congregations of potential targets and offenders. The Metro system provides information on the interchange and connection characteristic of the stations on its website.

Fig. 1 The Washington DC Metro System (Source: WMATA 2014)

Remoteness This is a measure for the remoteness of the station from the center of the transit system. A factor variable was produced with an exploratory factor analysis of two dichotomous variables in STATA using the polychoric and matrix commands (rho = 0.71, eigenvalue = 1.21). The first binary variable, "End station," indicated if the station was an end of the line station (Yes = 1, No = 0). The second binary variable, "Daily Parking," indicated if the station provided daily parking (Yes = 1, No = 0). Remoteness is a node characteristic of a transit system and is expected to be a crime-attracting characteristic because literature has shown that remote stations provide better opportunities for certain crimes and overall experience higher rates of crimes (e.g., vandalism, disorderly conduct). The Metro system provides information on the parking around stations and end stations are defined as the stations at the end of each line (i.e., the Glenmont, Shady Grove, Vienna, Greenbelt, New Carrollton, Branch Avenue, Huntington, Franconia-Springfield stations).

Accessibility and activity level (AAL) This variable measures the ease of access and the potential level of activity around the stations. A factor variable was produced with principal component analysis of five scale variables in SPSS. The first variable measured the number of retail businesses, personal and lodging services in the block group in 2008 in which the station was housed ($N = 5{,}649$). The second variable measured the number of entertainment and recreation, health, legal, and education services in the block group in 2008 in which the station was housed ($N = 3{,}773$). The third variable measured the number of legal, social, and public administration services in the block group in 2008 in which the station was housed ($N = 9{,}162$). The data for these three variables were extracted from the National Establishment Time Series Database. The fourth variable measured the walkability level around stations. This data was acquired from *Walkscore.com* which "measures the walkability of any address based on the distance to nearby places and pedestrian friendliness" (Walkscore 2014). This is a score between 0 and 100 for which lower scores represent car-dependent neighborhoods and high scores represent easily walkable neighborhoods. The fifth variable measured the ridership in 2008 at the stations. Ridership refers to the total number of entries and exits at each station. The ridership data were acquired from Washington Metropolitan Area Transit Authority. To reflect the change in ridership at peak and non-peak hours, the AAL variable was calculated for each time period's ridership. The result of this computation was three factor variables representing AAL at different times: AAL peak (eigenvalue = 3.29), AAL nonpeak day (eigenvalue = 3.36), and AAL nonpeak night (eigenvalue = 3.21). AAL is a place characteristic of a transit system and assumed to be a crime-generating characteristic of a station.

Socioeconomic status (SES) This measures the SES level in the block group in which the stations are housed. A factor variable was produced with principal component analysis of five scale variables in SPSS (eigenvalue = 3.30). The five variables that were measured in the block group are: 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. The data for these variables were extracted from the 2008–2012 American Community Survey estimates. SES is a place characteristic of a transit system and low SES is expected to be a crime-attracting characteristic.

Other crimes This place variable measures the prevalence of specific crimes at the stations. Other crimes are crime-attracting place characteristics of a station. For the disorderly conduct dependent variable, the other crimes included in the analysis as independent variables are other measures of unruly conduct: alcohol violations ($N = 959$), public urination ($N = 398$), and vandalism ($N = 28$). Stations with other unruly conduct incidents are expected to provide opportunities for disorderly conduct. For the robbery dependent variable, the other crimes included in the analysis as independent variables are aggravated assault and larceny. Stations with a high number of larceny and aggravated assault are expected to experience more robberies. For the larceny dependent variable, the other crimes included in the analysis as an independent variable are robberies. Stations with a high number of robberies are expected to have more larcenies. For the aggravated assault dependent variable, the other crimes included in the analysis as an independent variable are robberies. Robberies are also violent crimes and stations with a high number of robberies are expected to provide better opportunities for aggravated assaults.

Results and discussion

Temporal Patterns

Table 1 demonstrates the hourly differences in the counts of disorderly conduct, larceny, aggravated assault, and robbery. The majority of larcenies were observed to take place during peak hours, followed by non-peak day hours, with the lowest number occurring during non-peak night hours. This observation suggests that larceny, being a crime against property, is more likely to be affected by the crime-generating characteristics of places at day hours and peak-hours when people especially travel more. Disorderly conduct, on the other hand, was observed to be almost equally divided between non-peak night hours and peak hours, with a very small number of disorderly conduct incidents happening during non-peak day hours. Nearly 56 % of the aggravated assaults were observed during the non-peak night hours suggesting that, as also supported by the literature (Ceccato 2013), aggravated assaults are more likely to be happening at times when there is less people and less guardianship at stations. Comparatively speaking, robberies were the most homogeneously distributed crime across different times of the day. Eighty percent of the robberies were almost equally divided between peak hours and non-peak night hours, and the remaining 20 % of the robberies in 2008 happened during non-peak day hours. Being a crime against both persons and property, robbery is likely to be nourished by the opportunities provided by both dense and less dense populations in and around stations—where dense populations offer more targets and less dense populations offer less guardianship (Clarke et al. 1996).

The kernel density[1] of the counts of larceny, aggravated assault, robbery, and disorderly conduct at stations were calculated in ArcMap for peak, non-peak day, and non-peak night hours. Figures 2, 3, 4, and 5 demonstrate the hourly changes in the density of these crimes. In these figures the high density areas for crimes are symbolized in dark blue.

Figure 2 illustrates the density of robberies at different times of the day. Robberies, at any time of the day, were observed to be denser around the train stations in DC. Robberies were observed to cluster at the stations in the center of the district during non-peak day hours. Non-peak night and peak hours robberies were observed to

Table 1 Hourly Differences in crime counts: peak hours, non-peak day hours, and non-peak night hours

	Disorderly Conduct		*Larceny*		*Aggravated Assault*		*Robbery*	
Time of the Day	N	%	N	%	N	%	N	%
Peak hours	72	42.60	142	60.68	10	29.41	170	40.38
Non-peak Day Hours	11	6.51	54	23.08	5	14.71	97	23.04
Non-peak Night Hours	86	50.89	38	16.24	19	55.88	154	36.58
Total	169	100.00	234	100.00	34	100.00	421	100.00

cover a larger geography of stations to the mid-north, south, and southeast of the district. The stations close to Columbia Heights, which fall to the north of the Metro Center, experienced more robberies during non-peak night hours.

As shown in Fig. 3, high density larcenies during peak hours were relatively homogeneously distributed in all DC, Virginia, and Maryland jurisdictions. During non-peak day hours high density larcenies were observed in the center and north of DC, and at remote Maryland stations. At non-peak night hours majority of larcenies were observed outside of DC, majorly in Maryland, remote from the Metro Center.

As illustrated in Fig. 4, high density aggravated assaults were more geographically dispersed than robberies. However, it should be noted that 2008 aggravated assaults were rare in the metro system. The aggravated assault incidents during non-peak day hours were observed to be in the east of DC, and at Virginia and Maryland stations close to DC. Peak hour aggravated assault incidents were observed in DC and Virginia. Non-peak night hour aggravated assaults were concentrated at stations close to the Metro Center station in DC, at remote stations in Maryland, and at Virginia stations close to DC.

Disorderly conduct incidents were concentrated at stations in the center and northwest of DC during peak hours (see Fig. 5). Non-peak day hours disorderly conduct incidents were observed at DC stations close to the Metro Center Station and to the north of Metro Center. Night non-peak hours disorderly conduct incidents were observed at stations close to the Metro Center, to the south of the Metro Center and close to end stations.

Results of the negative binomial regression analysis

Robberies

Table 2 illustrates the results of the regression analysis for robberies using incident rate ratios (IRR). The regressions conducted for robberies show that during peak hours, robberies' rate ratio at a station is expected to increase by the increase in the number of aggravated assaults and the level of activity and accessibility of stations. Furthermore, during peak hours, rate ratio for robberies is higher at stations with low SES scores. As further illustrated in Table 2, during non-peak day hours, the only factor that is related with the increased rate ratios for robberies is the connectedness of the stations. During non-peak day hours, a station that is connected better to the rest of the transit system has a higher rate ratio for robberies. During non-peak night

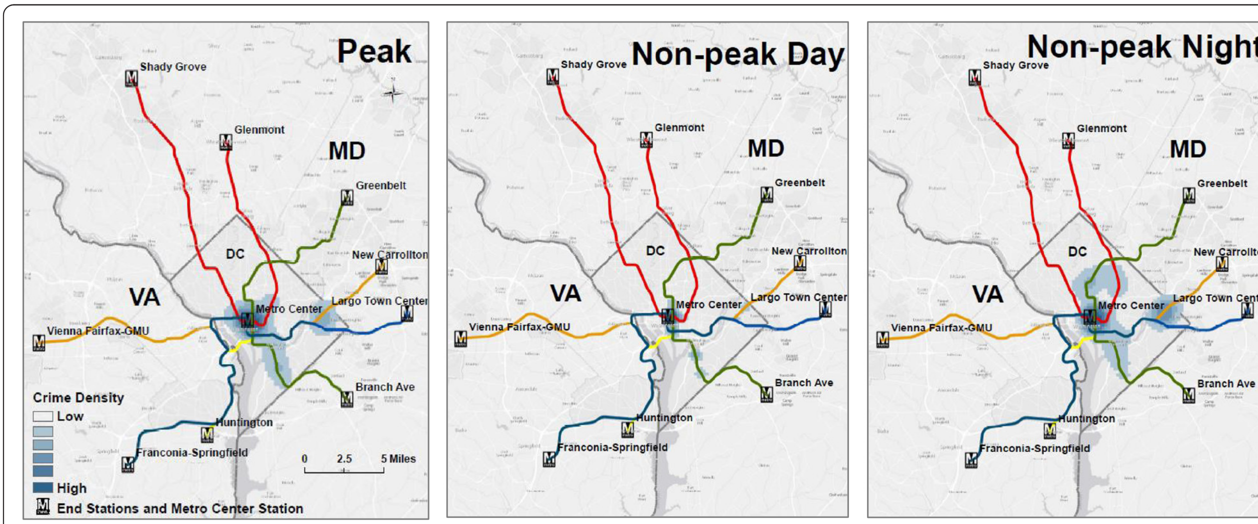

Fig. 2 Robbery density at peak, non-peak day, and non-peak night hours

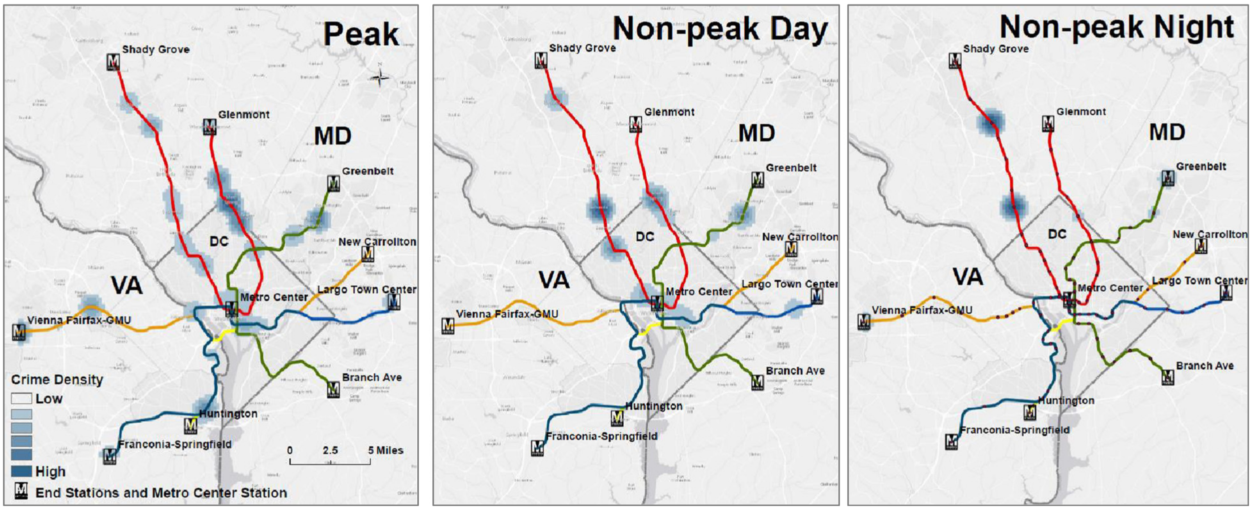

Fig. 3 Larceny density at Peak, non-peak day, and non-peak night hours

hours, on the other hand, robbery rate ratio is higher for stations that have a high accessibility and activity level and a low SES level.

For the robbery dependent variable, the regression analysis shows that: 1) the level of other crime or the level of SES at a station can act as a *place-based crime attractor* for robberies, and 2) the accessibility and activity level of a station or the connectedness of a station can act as a *nodal crime generator* or a *place-based crime generator* for robberies. Furthermore, the analysis of the robberies according to the daily rhythms of human activity shows that different combinations of both nodal and place-based crime-generating and crime-attracting characteristics of places at stations act as situational catalysts for robberies.

Larcenies

Table 3 illustrates the results of the regression analysis for larcenies using IRR. The rate ratio for larcenies is positively correlated with the connectedness of the station during non-peak day hours. Based on these results, stations that provide access to the rest of the rail system can be assumed to be ideal nodal crime generators for crimes against property such as larceny and robbery during peak and non-peak day hours. The biggest difference of larcenies from robberies is the role of SES on the rate

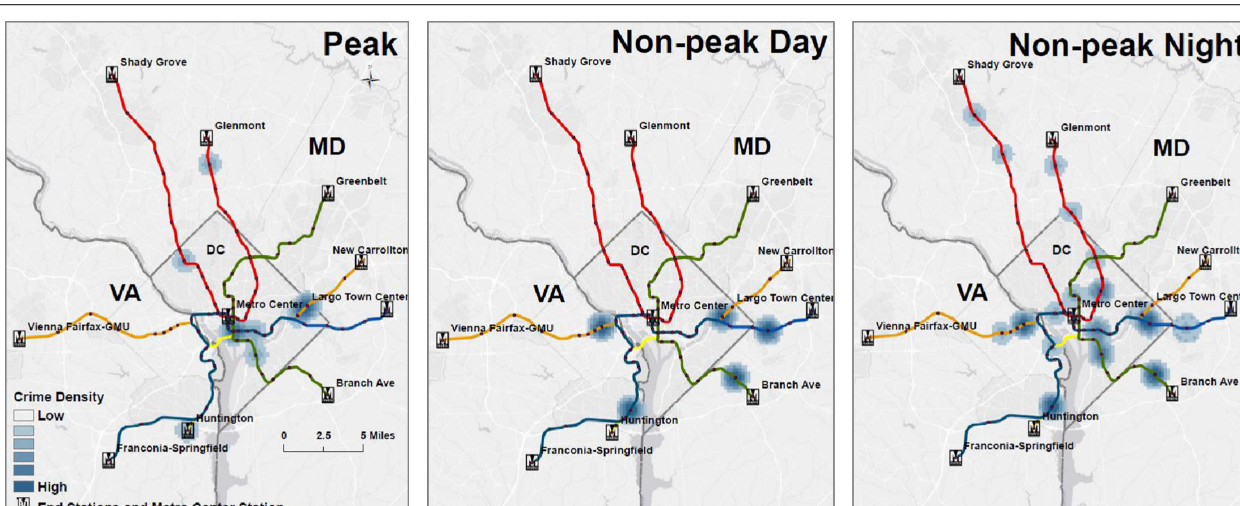

Fig. 4 Aggravated assault density at peak, non-peak day, and non-peak night hours

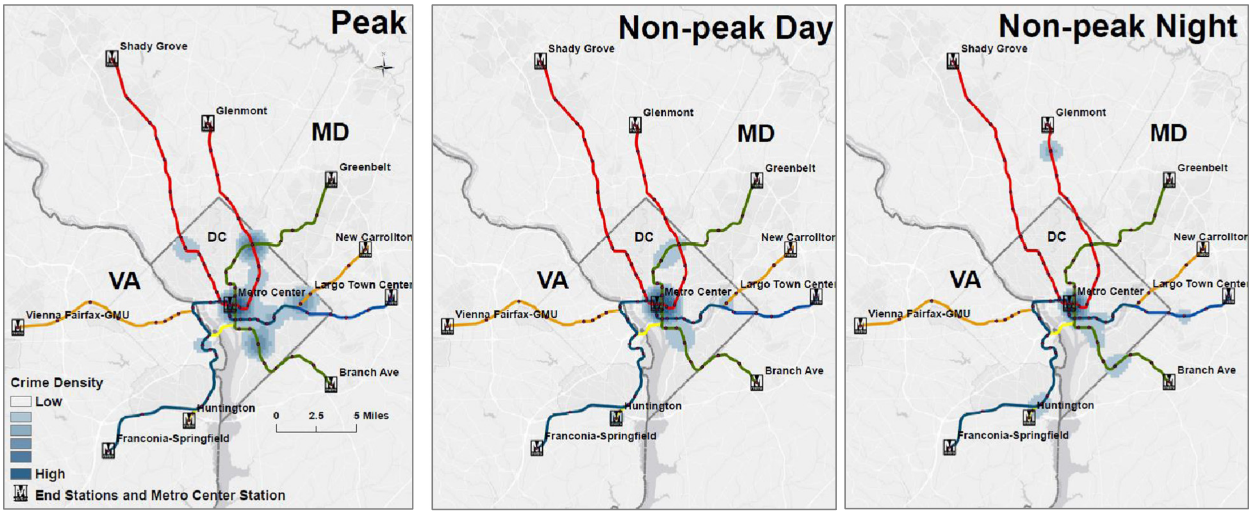

Fig. 5 Disorderly conduct density at peak, non-peak day, and non-peak night hours

ratios of these two crimes. While SES is negatively correlated with the rate ratio of robberies, it is positively correlated with rate ratio of larcenies (see Table 2 and Table 3). These conflicting findings suggest that while robberies thrive particularly on crime-attracting opportunities (such as low SES, presence and proximity to other crimes etc.), geographies with higher SES levels and less crime might be providing better opportunities for larcenies. Based on the results from this regression analysis larceny might be concluded to be positively correlated with crime-generating characteristics of a node or place, rather than crime-attracting ones.

Aggravated assault

As shown in Table 4, the only significant predictors for aggravated assaults were the robberies at stations during peak hours. As indicated earlier, in the year 2008 aggravated assault were very rare events at Metro stations. The lack of significance of other factors for this particular variable might be related to the rareness of this crime outcome at Metro stations in 2008. That said, the rate ratios of aggravated assaults are observed to increase with increased counts of robberies (see Table 4). Thus, aggravated assaults appear to be affected by the place-based crime-attracting characteristics of a station.

Table 2 Results of negative binomial regression analysis for robberies

	Robbery		
	Peak	Non-peak day	Non-peak night
Incident Rate Ratios of Node Variables			
Connectedness (crime generator)	2.822	4.459*	2.083
Remoteness (crime attractor)	0.591	0.414	0.745
Incident Rate Ratios of Place Variables			
Accessibility and Activity Level (crime generator):			
AAL_Peak	1.476†	–	–
AAL_Non-peak day	–	1.183	–
AAL_non-peak night	–	–	1.525*
SES (crime attractor)	0.734†	0.780	0.541***
Other Crimes (crime attractor):			
Larceny	0.982	0.974	0.755
Aggravated Assault	2.345*	1.856	1.227
	$R^2 = 0.06$	$R^2 = 0.04$	$R^2 = 0.06$

*Significant at 0.01 p-level
***Significant at 0.001 p-level
†Significant at 0.1 p-level

Table 3 Results of negative binomial regression analysis for larcenies

	Larceny		
	Peak	Non-peak day	Non-peak night
Incident Rate Ratios of Node Variables			
Connectedness (crime generator)	7.026**	4.020	2.928
Remoteness (crime attractor)	2.321†	0.981	6.688
Incident Rate Ratios of Place Variables			
Accessibility and Activity Level (crime generator):			
AAL_Peak	0.736	–	–
AAL_Non-peak day	–	0.965	–
AAL_non-peak night	–	–	2.782†
SES (crime attractor)	1.726**	1.651*	1.192
Other Crimes (crime attractor):			
Robbery	0.968	0.962	0.760
	$R^2 = 0.06$	$R^2 = 0.04$	$R^2 = 0.06$

*Significant at 0.05 p-level
**Significant at 0.01 p-level
†Significant at 0.1 p-level

Disorderly conduct

Table 5 shows the results of the regression analysis for disorderly conduct. Similar to the other dependent variables tested in this study, the rate ratios for disorderly conduct are also observed to be positively related to the number of other crimes at the station. For disorderly conduct, an increase in vandalism and public urination increases the rate ratio for disorderly conduct especially during non-peak night hours. The IRR value for the "remoteness" variable in Table 5 further suggest that during non-peak night hours, stations that are farther away from the metro center are more likely to experience disorderly conduct incidents. This finding is in keeping with Ceccato's (2013) finding that end of the line stations provide specialized opportunities for crime (such as vandalism, graffiti, and disorderly conduct).

To summarize:

- Remote stations were attractors of larcenies during peak hours and they were attractors of disorderly conduct during non-peak night hours.
- Stations that have connections to the rest of the rail system were generators of larcenies and disorderly conduct during peak hours and they were generators of robberies during non-peak day hours.

Table 4 Results of negative binomial regression analysis for aggravated assaults

	Aggravated Assault		
	Peak	Non-peak day	Non-peak night
Incident Rate Ratios of Node Variables			
Connectedness (crime generator)	3.623	1.360	0.704
Remoteness (crime attractor)	1.634	0.593	0.749
Incident Rate Ratios of Place Variables			
Accessibility and Activity Level (crime generator):			
AAL_Peak	0.348	–	–
AAL_Non-peak day	–	0.364	–
AAL_non-peak night	–	–	0.847
SES (crime attractor)	1.456	0.754	0.779
Other Crimes (crime attractor):			
Robbery	1.322**	1.194	1.101
	$R^2 = 0.15$	$R^2 = 0.13$	$R^2 = 0.04$

**Significant at 0.01 p-level

Table 5 Results of negative binomial regression analysis for disorderly conduct

	Disorderly Conduct		
	Peak	Non-peak day	Non-peak night
Incident Rate Ratios of Node Variables			
Connectedness (crime generator)	9.320*	3.544	1.242
Remoteness (crime attractor)	0.846	0.804	4.437*
Incident Rate Ratios of Place Variables			
Accessibility and Activity Level (crime generator):			
AAL_Peak	1.007	–	–
AAL_Non-peak day	–	1.278	–
AAL_non-peak night	–	–	1.260
SES (crime attractor)	1.438	0.786	0.830
Other Crimes (crime attractor):			
Alcohol Violations	1.161	1.161	0.977
Vandalism	3.101	1.100	2.264**
Public Urination	1.155†	1.048	1.128**
	$R^2 = 0.06$	$R^2 = 0.11$	$R^2 = 0.21$

*Significant at 0.05 p-level
**Significant at 0.01 p-level
†Significant at 0.1 p-level

- Accessible stations with a high potential for human activity were crime generators for robberies and larcenies during non-peak night hours.
- Stations which were housed in the block groups with low SES were crime attractors for robberies during peak hours and non-peak night hours.
- Stations which were housed in the block groups with high SES were crime attractors for larcenies during peak and non-peak day hours.
- Stations that experienced other crimes were crime attractors for robberies and aggravated assaults during peak hours, and they were attractors for disorderly conduct during non-peak night hours.

Overall the findings from this study not only suggest that stations assume different nodal and place-based crime-generating and crime-attracting characteristics, but also these roles vary for different crimes and different times. All of the indicators included in this analysis were observed to be related to different crime outcomes at different times. From these indicators particularly the level of activity and accessibility of the station, the level of crime at the station, and the connectedness of the station to other stations were consistent indicators that had a positive correlation with crime rate ratios. Different characteristics of the station—such as being a remote station or belonging to a high or low SES block group—were identified to be significant correlates for particular crime outcomes such as disorderly conduct, robbery, or larceny.

The results from this study show similarities with the studies by Ceccato (2013); and Ceccato and Uittenbogaard (2014) in the sense that center stations (with more activity in and around stations) and end stations provide specific opportunities for particular crimes, and these opportunities are more pronounced at certain times of the day. The results also confirm the authors' findings that opportunities for different crimes at stations are dependent on the immediate and broader environment in which the stations are situated, and these opportunities vary temporally. In contrary to Ceccato's (2013) findings that most crimes take place at night, larcenies in Metro were observed to take place more during peak-hours, and robberies were equally distributed during non-peak nigh hours and peak hours. Furthermore, crime incidents at Metro are as frequent as disorderly conduct incidents. This finding might be attributed to relatively low crime and disorder level at Washington, DC, Metro in comparison to other large subway systems (La Vigne 1996a). The results from this study also confirm Newton et al.'s (2014) finding that crimes at subway stations are affected by the accessibility of the stations, characteristics of the station, and the characteristics of the immediate environment of the station.

Conclusion

Implications for environmental criminology and crime prevention

Rail stations are criminogenic places. However, as illustrated by the findings of this study, stations experience different crimes at different times. With this study we adapted some indicators of node-place modeling to crime analysis to understand the crime-generating and crime-attracting characteristics of stations at different times. These findings contribute to the current literature on environmental criminology by evidencing that a station can act as a crime generator or a crime attractor for the same crime or different crimes at different times of the day. The analysis combined micro geographical data on station characteristics and socio-demographic indicators and analyzed the effects of these factors on crime considering the shifts in the temporal rhythms of human activity.

The findings of the study have particular implications for crime prevention. This study shows that crimes at stations should not be interpreted independent of the immediate and larger environment in which the station is housed in. Different crimes are more likely to happen at stations with certain nodal and place-paced characteristics at particular times. With this information crime prevention strategies can be targeted at and around stations that are more likely to experience particular crime outcomes at different times of the day. At stations that are likely to experience certain crime outcomes due to the high number of passengers or conversely due to low number of passengers at certain times of the day, the frequency of rail service and the design and other security characteristics of the station (such as patrols at and around stations) can be changed to mitigate the crime risk. At stations that are experiencing more crimes due to other crimes at the station or the level of social disorganization around the station, broader crime prevention efforts can be adapted. These efforts include: curfews for certain criminogenic land uses, increased safety measures and increased police patrol around criminogenic land uses close to stations, increasing the resilience among the residents of a crime-prone neighborhood, and a problem-oriented multi-stakeholder approach to the complex crime problem in the station vicinity.

Limitations and future research

As indicated earlier, this study did not test the influence of station design and management characteristics on crime outcomes because an earlier study by La Vigne (1996b) evidenced that design and management characteristics were uniform for Metro stations. Future studies on crime at and around metro stations can further explore the effect of this by a thorough examination of new design and management characteristics at Metro stations.

In this study, five year estimates of American Community Survey (ACS) were used to operationalize the SES variable. ACS data is known to have larger margins of error compared to the margins of error for long-form census data. However, this was an acceptable trade-off for measuring SES at a smaller unit of analysis. ACS enabled us to measure SES at the block group level which is smaller than the smallest unit of analysis of SES for census data, the census-tract level. Future studies should consider more specific descriptions of the nodal and place based criminogenic characteristics of stations and use different temporal groupings for the analysis of a broader variety of crimes.

Endnote

[1]The output cell size for the kernel density analysis was 300 feet. Search bandwidth was 1,000 feet.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

YI-E and NLV conceived the study. YI-E conducted all data cleaning and analysis, and drafted the manuscript. NLV advised on the design of the study, provided statistical guidance, and helped to draft the manuscript. Both authors read and approved the final manuscript.

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