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Modelling the effects of street permeability on burglary in Wuhan, China

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A R T I C L E I N F O

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A B S T R A C T

Crime is spatially concentrated as a result of many contributing factors. In this study, we evaluate the influence of street network permeability on the spatial distribution of burglary in Wuhan, China. First, we review previous research on the effects of street permeability on crime as well as the underlying interpretations and assumptions. Then, we explain the method used in this study and evaluate the influence of street permeability, together with a series of socio-economic and public facilities variables, on burglaries at the street segment level. The results suggest that streets with higher local (non-local) permeability are expected to be safer (dangerous).

1. Introduction

Environmental criminology contends that physical environmental features play a central role in the formation of crime's spatial distribution (Brantingham & Brantingham, 1999). The street network serves as the "skeleton" of an area because it reveals where the environmental components of the area are located (Davies & Johnson, 2015). As movements of people along roads are largely constrained as they travel from one place to another, the street network also facilitates the occurrence of motivated offenders with suitable targets and a lack of qualified guardians at a specific place and time, presenting conditions under which criminal activity will occur (Brantingham & Brantingham, 1999; Frith, Johnson, & Fry, 2017).

The street segment is a natural micro-level unit of analysis that has been widely adopted to better identify the environmental factors contributing to the formation of crime patterns (Davies & Johnson, 2015; Groff, 2017). In this study, a street segment represents the section of road that connects two intersections. When discussing the relationships between road segments and crime, the concept of street permeability is frequently applied (Birks & Davies, 2017; Brantingham & Brantingham, 1993; Johnson & Bowers, 2010). Permeability refers to the manner in which street configuration impacts the extent to which the neighborhood is opened to external pedestrian and vehicular traffic, and hence influences criminal activity (Cozens & Love, 2009; Johnson & Bowers, 2010). Some parts of a road structure are less permeable and difficult to use to arrive at a destination via a reasonably direct route; by contrast, others are more permeable and easier to reach because they are well connected (Frumkin, Frank, & Jackson, 2004).

In this study, we examine the influence of street permeability on burglary in one of the largest metropolitan cities in central China. The research is carried out in a large district by using a three-year dataset to assure the reliability of the results. In addition, socio-economic and facilities variables are taken into account, as these factors influence crime patterns.

2. Literature review

This study focuses on the effects of street permeability on burglary, which belongs to the area of environmental criminology (Brantingham & Brantingham, 1999). According to this theory, the physical environment is a crucial consideration when offenders choose targets (Nee & Taylor, 2000). For example, Wright and Decker (1994) demonstrated that "layout" features such as the location of the house on the street (indicating ease of access and escape) and its size (indicating level of wealth) are the most important factors; they also showed that burglars tend to avoid public dwellings and target affluent residences. Indeed, the possibility of a neighborhood being chosen for burglary is positively correlated with its spatial proximity to where the burglar lives, its accessibility, its lack of guardianship, and the number of possible objects in the neighborhood (Bernasco & Nieuwbeerta, 2004). High-rise residences with elevators, long dark corridors, and easy access to the public are prone to crime (Mayhew, 1979). Burglars prefer unoccupied houses as they are less guarded (Waller & Okihiro, 1978), while detached houses are naturally more vulnerable because they are easy to

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enter and there are usually multiple escape routes (Nee & Taylor, 2000).

The physical environment is also correlated with the popular repeat and near-repeat phenomenon of burglaries, namely shortly after a location is burgled, the same location and locations nearby are exposed to an elevated risk of victimization (Bernasco, 2008). Bernasco (2008) demonstrated that after committing a burglary, the offender gains knowledge about the location of the property, how it can be accessed, the interior layout, and places where precious items are to be found. Hence, a rational burglar tends to return to that property or share information with other burglars (Bowers & Johnson, 2004). These same offenders or their associates are responsible for repeat and near-repeat burglaries (Bowers & Johnson, 2004). Moreover, compared with unrelated burglary cases, near-repeat burglaries show a certain similarity in burglars' modus operandi such as the means and point of entry (Bowers & Johnson, 2004).

As to the effect of street permeability on burglary, there are two main opposing perspectives, namely the "enclosure" and "encounter" models (Cozens & Love, 2009). According to the "enclosure" model, more "enclosed" or less permeable residential areas are safer. People are likely to visit certain places more frequently than other places in their routine everyday activities, such as their homes, workplaces, and places for entertainment and shopping (Cohen & Felson, 1979; Summers & Johnson, 2017). These frequently visited places constitute people's awareness spaces (Beavon, Brantingham, & Brantingham, 1994; Brantingham & Brantingham, 1993; Cohen & Felson, 1979). Rational choice theory further contends that burglars rarely aimlessly hunt for crime opportunities outside their awareness space; instead, they tend to select targets from places they already know (Brantingham & Brantingham, 1984; Nee & Taylor, 2000). For example, Felson (1993) demonstrated that burglars hunt for a property within attractive areas noted during their routine activities. Davidson and Davidson (1981) also found that burglars choose familiar properties near where they live. Less permeable areas, however, are less accessible and hence only known to local residents; they are less likely to appear on non-residents' daily routes and thus less likely to lie in the awareness space of potential offenders (Dovey, 2000; Summers & Johnson, 2017).

When considering the "enclosure" model, increased permeability means more access for all citizens (potential offenders included) (Cozens & Love, 2009). Because of the mixed use of spaces by residents and non-residents, the territoriality of neighbors would decrease as it is not clear who should take responsibility for the natural surveillance of the neighborhood (Johnson & Bowers, 2010). Therefore, the more permeable a place is, the more opportunities for crime there are (Cozens & Love, 2009). Hence, less permeable areas are safer because non-residents are less likely to visit these places, the ownership of these neighborhoods is evident, and neighbors act in their role as natural guardians (Newman, 1972).

Newman's (1972) proposed idea of a defensible space also supports the "enclosure" model. As access to such spaces is usually restricted, they are mostly dominated by local residents. In this way, residents' sense of territoriality or responsibility over a residential space motivates them to act as natural guardians. Non-residents are obvious in these areas and thus easy to recognize and challenge (Cozens & Love, 2009; Newman, 1972). A modern method for crime control, referred to as Crime Prevention through Environmental Design (CPTED), is based on the defensible space concept (Jeffery, 1969; Sohn, 2016). CPTED is proposed to reduce fear and the occurrence of crime by designing the built environment properly (Crowe, 2000). Based on design principles such as territoriality and access control, it suggests the separation of private and public areas, use of road closures, and development of physical barriers to deny potential offenders' access (Sohn, 2016). In summary, a non-permeable street layout is an effective design for crime reduction (Cozens, 2008; Cozens, Pascoe, & Hillier, 2004; Town, Davey, & Wooton, 2003).

By contrast, the "encounter" model suggests that permeable streets are safer (Dovey, 1998). Streets with high permeability are well connected to the street network and provide easy access for arrival at a destination. Such "central" streets promote the use of permeable areas by all citizens. The abundant use of the street is beneficial because more strangers will be present, increasing the level of "eyes on the street." These strangers are therefore beneficial to community safety because, together with residents, they provide informal surveillance in that space (Jacobs, 1961). In this way, less crime could be expected on streets with the highest permeability (Davies & Johnson, 2015). Less permeable spaces with few people are dangerous because they are likely to suffer more crimes as there are few witnesses (Beavon et al., 1994).

The evidence of the "encounter" model is mainly supported by studies using the space syntax methodology (Cozens & Love, 2009). For example, Jones and Fanek (1997) controlled for the influence of demographic characteristics and examined the effect of spatial configuration on crime. They found that crime was concentrated in isolated and less accessible streets, while lower crime rates should be expected in areas with higher permeability (see also Chih-Feng Shu, 2000). Hillier (2004) suggested that community safety could be optimized through spatial design. Permeable environments such as reasonably regular street layouts, well-integrated streets, and constituted linear streets are secure (Hillier, 2004).

3. Research design

3.1. Study region

The study region is Jianghan District, Wuhan City, China. Wuhan is a megacity and is the political, economic, financial, cultural, educational, and transportation center of central China (Bureau, 2014). It is composed of seven urban districts and six suburban districts, and is divided into three parts by the Yangtze and Hanshui Rivers: Han Kou, Han Yang, and Wu Chang (Ye, Xu, Lee, Zhu, & Wu, 2015). As shown in Fig. 1, Jianghan District is located at the confluence of the two rivers in the center of Wuhan City. It is the most densely populated district with an area of 33.43 km^2 and a population of about 710,000 (Bureau, 2014). It has convenient transportation facilities with a dense highway network and three subway lines. Hankou Railway Station, the largest railway station in central China, is also located in Jianghan District. Jianghan District also has convenient waterway transportation.

The district is the core area of financial business in Wuhan City. It has a well-developed service industry, including retail, finance, insurance, business, and tourism services. It also features well-equipped leisure and entertainment facilities such as squares, pedestrian walkways, and parks. However, as a developing city, this area is still under urbanization. There are five urban villages in the west and north as well as a large-scale CBD under construction in the southwest. A floating population of more than 100,000 live in this district (Bureau, 2014). The interaction of these complicated geographical, demographical, and economic features means that Jianghan District has a high level of crime.

3.2. Data

3.2.1. Crime data

An official residential burglary dataset was provided by the Wuhan Municipal Bureau of Public Security. These data comprised all residential burglaries that occurred between January 1, 2013 and December 31, 2015 (6982 cases). The location of each case was recorded as XY coordinates by using the World Geodetic System 1984. Each case was projected to the nearest street segment by using Geographical Information System software.

3.2.2. Road data

The road network geographic data were sourced from the Wuhan Police Geographic Information System (WH-PGIS). All the street

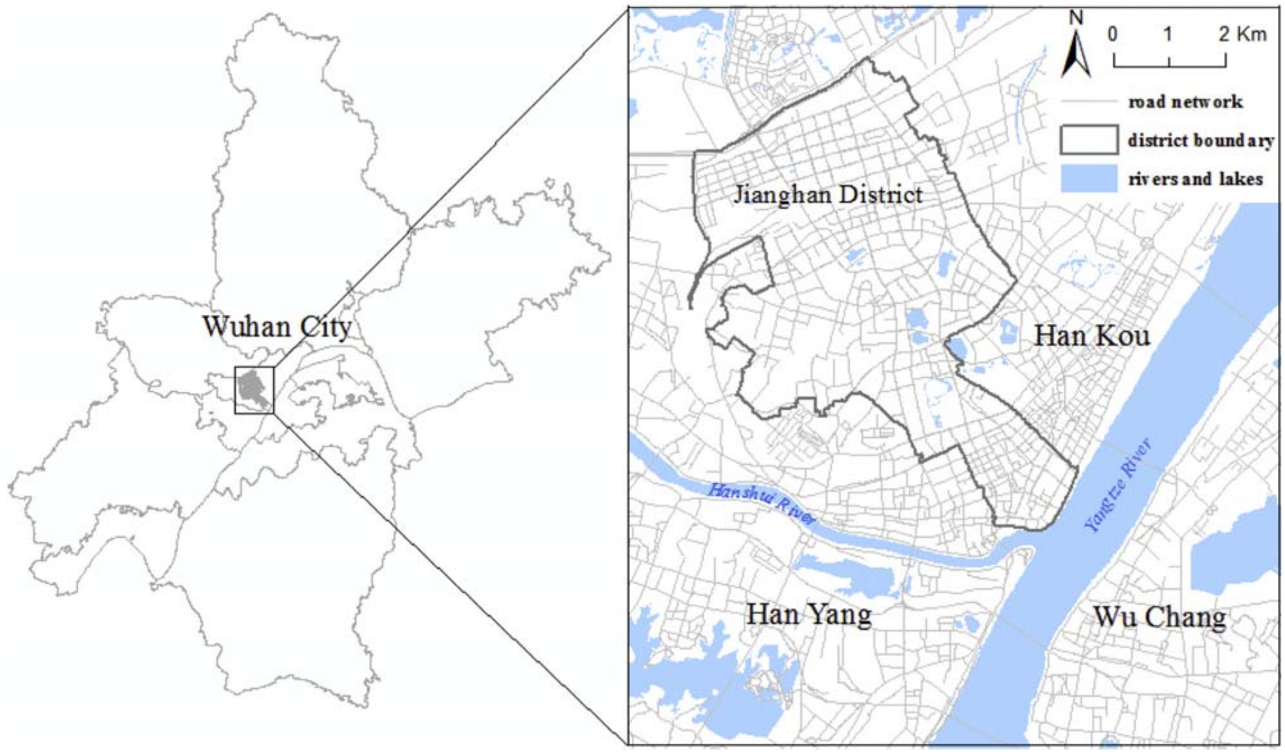

Fig. 1. Jianghan district in Wuhan.

segments within the Jianghan District were used along with a 3-km buffer around this area. This buffer was used to avoid the edge effect in the computation of road permeability, and the 3-km threshold was selected because it approximates Chinese residents' average daily vehicle journeys (2.7-km) (Ng, Schipper, & Chen, 2010). All the roads were divided at intersections. After this process, 761 road segments within the study area were obtained.

3.2.3. Socio-demographic data

The socio-demographic data included the number of households, age and gender structure, ratio of unemployed residents, and education level. The number of households represents the opportunities that a neighborhood “provides” for offenders. The age and gender structure was utilized to demonstrate the probability of crime. In line with previous research, the age range 15–30 years was chosen as the peak age of offenders in the study area (Wu et al., 2015). The gender structure was also included since gender divisions are considered as important to crime, with men being the major perpetrators of crime (Heidensohn, 1989). Debate has raged about the relationship between unemployment and crime, with some researchers arguing that unemployment promotes crime because the unemployed are without jobs and have financial needs (Cantor & Land, 1985). However, from the perspective of routine activities theory, the unemployed could act as guardians for their dwellings, indicating a negative correlation between unemployment and crime (Paternoster & Bushway, 2001). We used the ratio of unemployed residents to explore the relationship between unemployment and burglary in Wuhan City. Education level was used as a proxy for income level, as more educated people have higher salaries (Beaton, 1975) and are, by implication, more attractive to potential offenders.

3.2.4. Facilities data

We also considered the influences of various facilities data on burglary, including police-monitored street-viewing CCTV cameras, subway stations, and land-use features. CCTV cameras have a restraining effect on criminal activity (Caplan, Kennedy, & Petrossian, 2011). Subway stations influence the permeability of roads and provide escape routes for offenders. The “commercial” land-use feature (a kind of super-category composed of retail, service, recreation, and leisure facilities) could help people form their spatial awareness, and this has a positive effect on crime (Summers & Johnson, 2017); it was therefore taken into consideration. For each street segment, the network distance between its center point and the nearest CCTV camera and subway station was first determined and then the number of commercial land-use features was obtained.

3.3. Methods

Street “betweenness” is an effective way of evaluating street permeability (Davies & Johnson, 2015; Frith et al., 2017; Johnson & Bowers, 2010). Betweenness may be interpreted as an estimation of the permeability of a street segment (Davies & Johnson, 2015). The calculation of betweenness is conducted as follows:

(1) Find the center point i of each street segment e;
(2) Obtain the shortest path(s) between any two points i and j; the number of path(s) is denoted as σ_{ij}, and the number of the path(s) that traverse(s) segment e is denoted as $\sigma_{ij}(e)$. For a given segment e, we can obtain its betweenness centrality B_e:

$$B_e = \sum_{i,j \in S, i\sim j} \frac{\sigma_{ij}(e)}{\sigma_{ij}} \tag{1}$$

where S denotes the set of the center points of all the segments and $i \sim j$ means that there exists a path between i and j.

(3) By repeating step (2), we obtain the betweenness of all the other segments.

If the trips between i and j are restricted to be shorter than a certain length r, then we get

$$B_e^r = \sum_{i,j \in S, i\sim j} \frac{\sigma_{ij}(e)}{\sigma_{ij}} \tag{2}$$

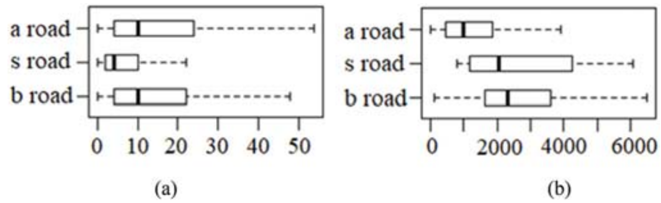

Fig. 2. Boxplots of road segment betweenness for various road classifications, using a metric radius of (a) 500 m and (b) 5000 m.

where $i \sim j$ means "there is a route of length at most r between i and j."

To represent the journeys through the network made by pedestrians or those who possibly live or have routine activities in the area, we limit r to 500 m; we denote the derived betweenness by local betweenness and permeability by local permeability. This distance threshold of 500 m is selected based on research that it is an acceptable pedestrian distance in urban areas as well as a reasonable distance from a residential building to multiple other types of urban land uses (Hasse & Lathrop, 2003). To represent the journeys by drivers or those who may live outside the area, we limit r to 5000 m; we denote the derived betweenness by non-local betweenness and permeability by non-local permeability. The distance threshold of 5000 m is chosen because 67.8% of trips in Wuhan City are less than or equal to 5000 m (Min, Xiaoning, & Hua, 2015).

To evaluate the impact of street permeability as well as other factors on burglary, we use the zero-inflated negative binomial (ZINB) regression model. This model accounts for the features of the response variables (numbers of burglaries on each street segment): (1) count variables; (2) overdispersion (the variance (20.05) is greater than the mean (9.17)); and (3) excessive zeros (26.30% are zero). It presumes that the outcomes are a combination of two data generation processes. One process is binary, which in our case determines whether a street segment will have any burglary at all; the other process is count, which in our case determines if a certain street is likely to have burglaries as well as their number.

The ZINB model fits two models concurrently. Model 1 is a logistic function (i.e., a binary model) used to determine the probability that the response variable is zero. Model 2 is a negative model (i.e., a count model) used to determine the expectation that the response variable is positive (Zahran, Brody, Vedlitz, Lacy, & Schelly, 2008). The ZINB model can be written as

$$P(y_i = j) = \begin{cases} p_i + (1 - p_i) g(y_i = 0) & \text{if } j = 0 \\ (1 - p_i) g(y_i) & \text{if } j > 0 \end{cases} \tag{3}$$

where p_i is the logistic function defined later and $g(y_i)$ is the negative binomial distribution given as

$$g(y_i) = P(Y = y_i | \mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_i + 1)} \left(\frac{1}{1 + \alpha\mu_i}\right)^{\alpha^{-1}} \left(\frac{\alpha\mu_i}{1 + \alpha\mu_i}\right)^{y_i} \tag{4}$$

where α allows for dispersion and u_i is defined as

$$\mu_i = \exp(\ln(t_i) + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki}) \tag{5}$$

and where t_i is the exposure variable (optional) and the x's is a set of k regressor variables.

The logistic function p_i in formula (3) is defined as

$$p_i = \frac{\lambda_i}{1 + \lambda_i} \tag{6}$$

$$\lambda_i = \exp(\ln(t_i) + \gamma_1 z_{1i} + \gamma_2 z_{2i} + \cdots + \gamma_m z_{mi}) \tag{7}$$

where t_i is also the exposure variable (optional) and the z's is a set of m regressor variables (note that the z's and x's may include common terms). The regression coefficients $\beta_1, \beta_2, \cdots, \beta_k$ and $\gamma_1, \gamma_2, \cdots, \gamma_m$ are estimated from a set of data.

4. Results

The roads in Jianghan District are classified into three grades: arterial roads (denoted as a-roads) that link traffic hubs such as railway stations and large public spaces such as shopping malls and parks; secondary trunk roads (s-roads) that serve as supplementary connections between arterial roads; and branch roads (b-roads) that link secondary trunk roads. Betweenness is a more direct proxy for permeability in comparison with road grade; road grade is mainly used for management purposes, while betweenness is an accurate way of estimating the usage potential of road segments and consequently collective awareness spaces (Davies & Johnson, 2015). Fig. 2 shows the betweenness of these different grades of roads. There is a substantial overlap between road grades regardless of whether a metric radius of

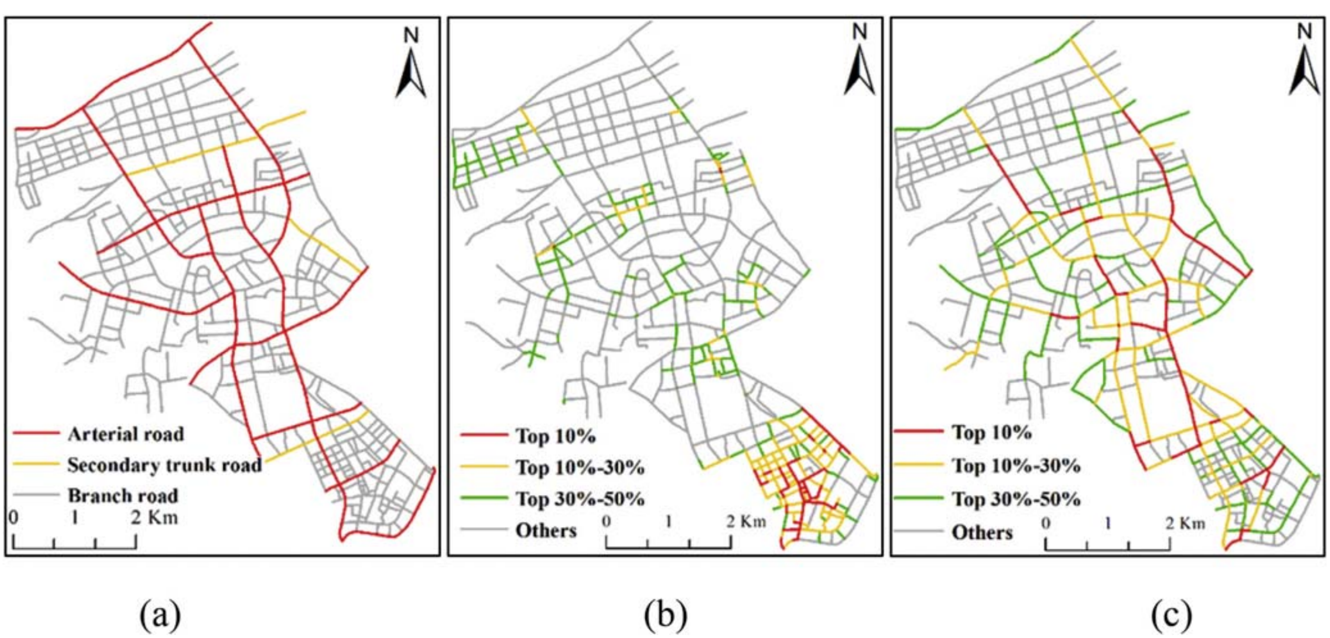

Fig. 3. Comparison between street grade and street permeability: (a) road grade; (b) street permeability (500 m); (c) street permeability (5000 m).

500 m or 5000 m is used. This finding could prove that road grade is a rough method of differentiating the permeability of street segments.

We visualize the road grades in Fig. 3(a) and the top 10%, top 10%–30%, top 30%–50%, and other parts of the street permeability value using a metric radius of 500 m in Fig. 3(b). Similarly, we visualize the street permeability value by using a metric radius of 5000 m in Fig. 3(c). There is a pronounced difference between the distribution patterns of road grade and permeability. When using a metric radius of 500 m, the segments with the top 10% and top 10%–30% of permeability are mainly concentrated in the southern area of the district; however, the segments with the top 30%–50% of permeability are dispersed at different parts of the district, and the distribution of segments with the top 10% and top 10%–30% of permeability is almost inconsistent with the distribution of road grade (Fig. 3(b)). However, the distribution of the top 10% and top 10%–30% of permeability when using a metric radius of 5000 m is largely consistent with the distribution of road grade (Fig. 3(c)). As shown in Fig. 3(b) and (c), the distribution patterns of the local and non-local permeability of the street network demonstrate a large difference. This can also demonstrate that the distribution of awareness space between local and non-local people differs, as do crime opportunities.

Since crime is concentrated in space (Davies & Johnson, 2015), we also tested the spatial concentration of burglaries in the study area, using linear nearest neighbor clustering statistics (Okabe, Yomono, & Kitamura, 1995). The result shows that the observed average nearest network distance is 25.52 m; this is statistically smaller than the expected value 60.49 m ($p < 0.001$), which means that burglaries are statistically concentrated in the network space.

In this study, we used Stata to fit the ZINB model. Table 1 lists the summary statistics of the variables and results of the ZINB regression models predicting burglaries on streets. The response variable (burglary) represents the number of burglaries in each segment. The independent variables are classified into four categories: road (road grade (a_road, s_road, b_road), road length (length)); socio-economic (proportion of young males (male), proportion of unemployed people (unemployed), proportion of highly educated people (educated), and count of households (household)); facilities (network distance to the nearest CCTV camera (camera), network distance to the nearest subway station (subway), and the count of commercial land-use features that are located on the street segment (commercial)); and permeability (local permeability (local_p), non-local permeability (nonlocal_p), and the network distances to the nearest segments with the top 10% of local (top_local_p) and non-local (top_nonlocal_p) permeability to represent the spatial concentration characteristic of burglaries). The diagnostic tests indicated no evidence of serious multicollinearity between these factors.

The results indicate that the parameter estimates of s-road and b-road are not significant, suggesting that burglaries on secondary trunk roads do not differ significantly compared with arterial roads. In addition, burglaries on branch roads do not have significant differences compared with arterial roads. However, road length is significantly and positively correlated with burglary (count: 0.0026). Furthermore, the binary parameter estimate of road length (binary: −0.0077) shows that the longer a street, the less likely it is to be immune from burglary. It is easy to interpret that a longer street means more households and, therefore, more crime opportunities.

All the socio-economic variables are significantly correlated with burglary, except male. Unemployed is significantly and negatively correlated with burglary (count: −2.4421), while educated (count: 0.8824) and household (count: 0.2960) are significantly and positively correlated with burglary. In addition, more households on a segment means a lower possibility of being immune from burglary (binary: −0.0135).

As for facilities, camera is negatively and significantly correlated with burglary (count: −0.0010), and a shorter distance means a higher possibility of being immune from burglary (binary: 0.0035). Subway is not significantly correlated with burglary. Commercial is positively correlated with burglary (count: 0.0456), and more commercial land-use features on a segment means less likelihood of being immune from burglary (binary: −0.5990).

In terms of permeability, local_p is negatively correlated with burglary (count: −0.0135), which implies that the larger the local permeability of a segment, the less burglary it is expected to experience. Further, larger local permeability means a higher possibility of being immune from burglary (binary: 0.0128). By contrast, nonlocal_p is positively correlated with burglary (count: 0.0007). The parameter estimates of top_local_p and top_nonlocal_p show that the farther away a segment is from a segment with the top 10% of local permeability, the larger the risk that it is expected to suffer from burglary (count: 0.0341); the farther away a segment is from a segment with the top 10% of non-local permeability, the smaller the risk that it is expected to suffer from burglary (count: −0.1237).

5. Discussion and conclusion

Compared with previous studies, which have presented the view

Table 1
Summary statistics of the variables and results of the ZINB regression models predicting burglaries on streets (Count represents the negative binomial portions of the models; Binary represents the logistic portions of the models).

Category	Variable	Description	Avg	Min	Max	S.D.	Count	Binary
Burglary	burglary	Count of burglaries that occurred on each street segment	9.17	0	321	20.04	–	–
Road	a_road	If the road is an arterial road = 1, otherwise = 0	0.23	0	1	0.42	–	–
	s_road	If the road is a secondary trunk road = 1, otherwise = 0	0.03	0	1	0.16	0.0865	0.8316
	b_road	If the road is a branch road = 1, otherwise = 0	0.74	0	1	0.44	0.2008	−0.0577
	length	The length of the street segment (meter)	232.42	31.15	1376.32	155.72	0.0026***	−0.0077**
Socio-economic	male	Proportion of young men (%)	0.13	0	0.71	0.10	0.1766	1.0278
	unemployment	Proportion of unemployed people (%)	0.09	0	0.59	0.11	−2.4421*	0.2343
	educated	Proportion of highly educated people (%)	0.08	0	0.75	0.11	0.8824**	−1.1336
	household	Count of households	374.05	0	4443	604.29	0.2960*	−0.0135**
Facility	camera	Network distance to the nearest CCTV camera (meter)	128.02	1.20	1348.36	237.42	−0.0010*	0.0035**
	subway	Network distance to the nearest subway station (meter)	1123.51	21.71	3927.64	753.12	0.0002	0.0006
	commercial	Count of commercial land-use features located on the street segment	1.78	0	43	3.01	0.0456**	−0.5990*
Permeability	local_p	The local permeability (500 m) of a street segment	17.48	0	150	21.67	−0.0135***	0.0128*
	nonlocal_p	The non-local permeability (5000 m) of a street segment	1949.59	0	17710	2111.61	0.0007*	−0.0002
	top_local_p	Distance to the nearest segment with the top 10% of local permeability	1381.86	0	4050.75	1082.08	0.0341*	0.4836
	top_nonlocal_p	Distance to the nearest segment with the top 10% of non-local permeability	2189.95	0	6683.34	1968.25	−0.1237**	0.4457

Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. The intercept terms are not listed. The Vuong test demonstrates that the ZINB model is more suitable than a standard negative binomial model (z = 5.48, $p < 0.001$); the likelihood-ratio test of alpha = 0 demonstrates that the negative binomial model is more suitable than the Poisson model ($\chi^2 = 39.05$, $p < 0.001$).

that permeable spaces either promote crime risk (Cozens & Love, 2009; Dovey, 2000; Newman, 1972) or reduce crime risk (Beavon et al., 1994; Davies & Johnson, 2015; Dovey, 1998), the results of this study indicate that a complex relationship exists between street permeability and burglary opportunities. Streets with higher local permeability are expected to be safer; in addition, if a street is near streets with high local permeability, it is also expected to be safer. Streets with high local permeability are mainly visited by pedestrians or those who have routine activities in the area (Davies & Johnson, 2015; Hillier, 1996), and the sense of territoriality or responsibility felt by these people plays a role in natural surveillance (Newman, 1972). Non-local residents in these areas are easily recognizable and usually questioned, such that potential offenders are largely discouraged from committing crime (Cozens & Love, 2009). This finding is consistent with Newman's (1972) defensible space theory. Streets with higher non-local permeability are expected to be dangerous, as are nearby streets. Streets with high non-local permeability are mainly visited by drivers or those who live outside the area (Davies & Johnson, 2015; Hillier, 1996). The existence of these non-locals and tourists renders these places dangerous because it is unclear who is responsible for the natural policing of the area. In other words, the mixture of local and non-local citizens weakens the territoriality and responsibility of local people (Johnson & Bowers, 2010; Newman, 1972). Thus, more non-local permeability means more crime opportunities.

As for the socio-economic factors, the unemployment rate has a negative impact on burglary, perhaps because unemployed people tend to stay at home, thus acting as "natural guardians" (Wu et al., 2015). The count of households and ratio of the highly educated have positive impacts on burglary. This is easy to understand since more households mean more crime opportunities and a higher ratio of highly educated people means higher levels of wealth (i.e., more attraction for offenders).

With respect to facilities, the distance to the nearest CCTV camera is negatively correlated with burglary. Hence, CCTV cameras have a restraining effect on burglars. The count of commercial land-use features promotes burglaries (i.e., more crime tends to occur in areas with more commercial land uses; Summers & Johnson, 2017). The high movement flows attracted by these non-residential land uses could shelter potential offenders and create more opportunities for crime (Stucky & Ottensmann, 2009).

The findings from this study not only validate criminological perception, but also have implications for crime prevention. Anti-crime measures (e.g., police patrols, CCTV cameras) should be instigated at the micro level. Police patrols should be deployed in targeted areas with high non-local permeability as well as neighboring areas. Furthermore, areas with a large number of households and a high ratio of highly educated people, or that contain commercial land uses, should have more crime prevention surveillance.

The methods used in this study have some limitations. First, the existence of one-way streets, turning restrictions, pavements, and other factors such as traffic capacity and speed can affect the possibility that a street segment may be selected on a travel route. As a consequence, the permeability of a certain street segment may change somewhat, and so therefore would the correlation between street permeability and burglary. Second, different types of commercial land-use features have various customer volumes, which will also affect crime opportunities. Third, interior burglars (i.e., those who commit burglaries in or near their residences) and exterior burglars (i.e., those who travel away from their residences to commit burglaries) have different perceptions of the selection of targets (Johnson et al., 2007), and we did not research this topic because of data limitations. In future work, we will examine route-choosing behavior and optimize the determination of street permeability. In addition, statistical models such as geographically weighted regression will also be conducted to account for the spatial heterogeneity of the variables.

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