MAPPING AN OPPORTUNITY SURFACE OF RESIDENTIAL BURGLARY

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The use of geographic information systems (GIS) to understand spatial patterns of crime and criminal behavior has become more prevalent in recent years, but with a few exceptions these analyses fall short of serving as predictive tools. The recent introduction of user-friendly, raster-based mapping software, designed primarily for environmental and planning purposes, offers new tools for examining and predicting crime and criminal behavior. By applying opportunity theories to the crime of residential burglary, this article examines the utility of raster-based mapping software for predicting desirable and undesirable locations of burglaries, as well as likely locations for crime displacement or diffusion. The findings reveal that the model holds promise for serving these prediction purposes.

Law enforcement officers and civilian crime analysts have been mapping crime with push pins and paper maps virtually since the time that police agencies were established. The introduction of client server technology in the late 1980s made a more useful mapping tool, geographic information systems (GIS), accessible to law enforcement agencies at a reasonable cost. At this point, a handful of law enforcement agencies and researchers began to experiment with computerized mapping programs. These programs automated mapping and allowed crime analysts and researchers to produce crime maps with increased speed. But significant dissemination of this technology did not take hold until the early 1990s, when personal computers powerful enough to handle large databases were coupled with software programs that did not require the disk space, memory, and processing speed of a mainframe or workstation computer.

Since the mid-1990s, the use of GIS in law enforcement agencies has grown tremendously (Mamalian and La Vigne 1998) and, in turn, has sparked great interest in GIS among criminal justice practitioners and researchers

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(Maltz 1993; McEwen and Taxman 1995). Crime mapping has emerged as an important tool in law enforcement agencies' efforts to scan for problems and develop what are often community/law enforcement collaborative responses to those problems (Groff 1996; La Vigne and Wartell 1998). GIS technology enables the visualization of crime patterns and trends and the identification of hot spots of crimes that have already occurred and come to the attention of the police. But ideally, the future of crime mapping lies in the ability to identify early warning signs across time and space and inform a proactive approach to police problem solving and prevention efforts.

Early warning systems necessitate predictive models that identify "hot spots" of crime and disorder as well as areas where crime is abating. To date, only a few published works exist on the use of GIS for predicting crime and criminal behavior, and these efforts represent highly sophisticated modeling methods employed by seasoned researchers (Brown 1998; Olligschlaeger 1997; Rossmo 1995).[1] The recent introduction of user-friendly, raster-based mapping software—designed primarily for environmental, city planning, and marketing purposes—allows us to examine how this software might be used by the average crime analyst to predict high- and low-opportunity areas of criminal offending as well as likely locations for crime displacement or diffusion. This article uses opportunity theories of crime to identify likely variables associated with desirable and undesirable targets for residential burglaries. We then undertake a pilot study to examine the utility of raster-based mapping software for predicting future hot spots of residential burglary based on a modeled opportunity surface.

THEORETICAL UNDERPINNINGS

The bulk of criminological theories have sought to explain factors associated with either individual propensity to commit (Akers 1973; Becker 1968; Merton 1957; Sutherland 1947) or refrain (Gottfredson and Hirschi 1990; Hirschi 1969) from criminal activity. Contrary to this traditional line of thought, which focuses on the individual offender and factors associated with his or her motivation, opportunity theorists concern themselves with the situational conditions under which offender motivation leads to commission.

Opportunity theories assume that crime is purposive and that individuals are self-determining: When people commit crime, they are seeking to benefit themselves, and certain calculations are involved in determining whether the criminal act will yield positive results (Clarke 1997). Such theories purport that offenders are influenced by situational and environmental features that provide desirable—or undesirable—offending opportunities. These theories are based on the belief that criminals engage in rational (if bounded) decision making (Becker 1968; Cornish and Clarke 1986) and that characteristics of the environment offer cues to the offender that promising opportunities for crime exist (Brantingham and Brantingham 1978, 1981; Cohen and Felson 1979; Harries 1980; Newman 1972; Wilson and Kelling 1982). The practical implications of these theories are that although criminals are motivated, they may nonetheless be deterred from committing crime if they perceive a potential target to be too risky, involve too much effort, yield too meager a profit, or induce too much guilt or shame to make the venture worthwhile (Clarke [1992] 1997; Clarke and Homel 1997). To identify desirable and undesirable target areas of residential burglary, we must rely on these theories to guide our choice of variables and determine how they will be operationalized.

METHOD

Based on the literature cited above, this article applies opportunity theories of crime to the specific offense of residential burglary by developing an opportunity surface based on data representing desirable and undesirable targets. Once the surface is created, it will be tested against a known data set of residential burglaries to determine its predictive power. Our goal is to assess the utility of raster-based modeling in aiding law enforcement with the prediction of likely and unlikely areas of crime, as well as potential displacement and diffusion areas. As such, the first step is to determine how powerful a model we can create using the simplest methods possible: those that are easily accessible to the average law enforcement analyst. Results from this initial project will likely lead to a more rigorous analytic approach that will be applied in future research.

The methods employed in this study are based on raster-based mapping using Spatial Analyst, an Environmental Systems Research Incorporated (ESRI)[2] product that operates as an extension to ArcView. Within a GIS, data features such as roads, streams, bus stops, and neighborhoods can be represented through the use of two models: vector or raster. GIS data that are represented as points, lines, or areas are termed vector data and are displayed in the same manner that features appear in a road atlas. In a raster-based GIS, such as that offered through the Spatial Analyst extension, the study area is divided into a series of equal-sized cells that together form a grid covering the geographic extent of the study area. Each cell has a value based on the amount of the variable that it contains. For example, each cell could have a number that represents the number of burglaries that occurred within it. The raster software enables the combination of data layers and their use in mathematical or algebraic expressions to model social and physical phenomena—analyses that are not possible with vector maps (Clarke 1997; ESRI 1998; Martin 1996).

Our method involves creating an opportunity surface from a sum of grids representing various environmental characteristics associated with high and low opportunities for residential burglary (see Data section below). Each characteristic, or variable, was classified into 0/1 categories reflecting absence or presence. (Details related to the analysis methods used are explained in the Analysis section.) Applying the above theories of criminal events to the development of this opportunity surface of crime, we posit that low-opportunity surfaces are those that require the greatest effort, suggest the greatest risk of apprehension, contain a significant presence of capable guardians, offer few environmental cues conducive to crime, and have a relative absence of signs of disorder. Likewise, high-opportunity surfaces—those presenting desirable opportunities for offending—are composed of the opposite factors found in a low-opportunity surface: low effort and risk, absence of capable guardians, and so forth. It should be noted that an important requirement when considering how to operationalize these characteristics is data availability.

Study Area

For this pilot study, we chose the Grier Heights neighborhood, one of the oldest African American neighborhoods in Charlotte, North Carolina (Hanchett 1986). Grier Heights was established in the late 1800s by a freed slave who bought the land and then divided it into individual lots that he sold to African Americans who were interested in becoming home owners (Hanchett 1986). The neighborhood thrived until the 1970s, when an aging population coupled with the influx of drugs initiated its decline.

The neighborhood has north-south and east-west arteries running along two of its borders. A stream runs along one remaining border and a railroad along the other. Grier Heights is approximately 410 acres and has 1,517 individual addresses. The neighborhood is less than one mile across both north/south and east/west. Its 1,138 residential units make up 32 percent of the total land area. Other major land uses include institutional (15 percent) and industrial (8 percent), which make up almost a fourth (23 percent) of the neighborhood. Another fourth (26 percent) of the neighborhood is vacant, and 8 percent is parkland. There are two commercial areas: one is a small strip center in the middle of the neighborhood, and the other is a larger strip center along Woodlawn Road, a major thoroughfare that defines the southeastern border.

The Grier Heights neighborhood has several advantages as a pilot site. First, we have access to a very rich geo-coded data set of the neighborhood, which includes variables normally associated with disorder and characteristics of the physical environment. In addition, there are an ample number of crime events to use in testing the model. Finally, given the data-intensive nature of this modeling exercise, a confined neighborhood makes this project more manageable for data analysis and interpretation.

DATA

The theories outlined above suggest a wide range of possible factors contributing to the attractiveness of a particular target for residential burglary; finding measurable, available data that accurately describe those characteristics, however, is difficult.

Explanatory Variables

Many of the explanatory variables used in the model were derived from prior research indicating that they had a significant relationship with crime in general or with residential burglaries in particular. Although other variables included in the model have not been demonstrated through research as being significant indicators of crime, they are nonetheless supported by the opportunity theories cited above. Although it would have been useful to examine the temporal ordering of events to determine whether the deteriorating environmental conditions made the area more attractive to burglars or the high number of burglaries sparked the deterioration of the physical environment, most of the explanatory variables were not available for the previous year, so we were unable to examine this element. Additionally, many of the explanatory variables used are fairly static from year to year, and thus temporal elements would have to be examined over longer time periods to yield meaningful results. A list of variables used, how they were coded, and the justification for their inclusion can be found in Table 1.

Test Variable: Residential Burglary

In this article, we are concerned with predicting residential burglary. Residential burglary was chosen because of the frequency of occurrence, availability of crime data, and the rich literature on the subject. To test our model, two separate analyses of burglary in the neighborhood were conducted, and in each case burglary was classified as a dichotomous variable. Burglary data were obtained from reported crimes to the police from November 15, 1995, to November 14, 1996, consisting of 103 events.

In the first analysis, we examined the differences between addresses that were burglarized and those that were not; burglary incidents were

TABLE 1: Operationalization of Variables

Variable	*Source/Coding*	*Justification*
Land use[a]	1 for residential, 0 for all others	Because we are focusing on the specific offense of residential burglary, only parcels that are residential would present likely targets.
Housing tenure	1 for renter occupied, 0 for owner occupied	Prior research (Greenberg, Rohe, and Williams 1982) suggests that areas with a higher percentage of renter-occupied housing units have weaker ties to the neighborhood, decreasing guardianship and creating a more desirable target for offenders.
Vacant unit	1 for vacant unit, 0 for occupied	Vacant buildings have been found to be desirable targets of crime (Spelman 1993).
Substandard housing[b]	1 if it had a reported housing code violation, 0 if not	Research suggests that substandard housing is associated with higher rates of crime on the block (Spelman 1993), and this is consistent with the "broken windows" theory (Kelling and Coles 1996; Wilson and Kelling 1982).
Nuisance violations[c]	1 if it had a reported nuisance violation, 0 if not	As with housing code violations, nuisance violations suggest a lack of guardianship and a high level of disorder.
Street lighting[d]	1 for dark areas, 0 for illuminated areas	Prior research indicates that lighting improvements are linked to reductions of crime of all types, including residential burglary (Painter and Farrington 1997).
Proximity to bus stop	Units within a 330-foot radius of a bus stop are coded 1, and all others are coded 0[e]	One of the ways that burglars learn about new targets is through their daily transportation routes and stops (Brantingham and Brantingham 1981; Rengert and Wasilchick 1985). Because pedestrians typically will only walk about a quarter mile (Calthrope 1993; Duany and Plater-Zyberk 1993; Nelessen 1994), only those areas within a quarter mile of the bus stop would likely be a part of a public transportation user's activity space.
Corner lots	Units are coded as 1 for corner lot or 0 for noncorner lot	Groff's (1996) prior research indicates that corner lots are at higher risk of residential burglary, and ethnographic studies suggest that this is because burglars perceive them to have fewer neighbors, and thus there is a reduced chance of being observed (Rengert and Wasilchick 1985).
Wooded areas and vacant lots	Areas adjacent to a wooded area or vacant lot are coded as 1, and all other areas are coded as 0	Buck, Hakim, and Rengert (1993) found that culs de sac that were surrounded by woods or adjacent to an abandoned railroad right-of-way were more likely to be burglarized. It follows that homes adjacent to vacant lots would also be more desirable due to the reduced chance that offenders will be observed during the

Proximity to major thoroughfare[f]	Areas within a two-block radius (1,000 feet) of major roads are coded 1, all others are coded 0	Wright and Decker (1994) found that burglars are continually "half looking" for potential targets. Because travel frequently occurs via major thoroughfares, burglars are more likely to be familiar with the residences along those roads. Burglars and robbers tend to extend their search area approximately two to three blocks from roads, entertainment places, and employment centers (Buck et al. 1993; Luedtke and Associates 1970:30).
Proximity to likely offenders	A doughnut-shaped buffer was created, coding units greater than 500 feet but less than 1,500 feet away from the residence of an arrested burglar as 1 and all others as 0[g]	The opportunity theories suggest that burglars will travel the minimum distance possible to commit a crime but will avoid the area immediately surrounding their home to reduce the risk of observation by those who can identify them (Brantingham and Brantingham 1981). These theories are supported by research identifying a zone of reduced criminal activity within a city block of juvenile delinquents' home addresses (Turner 1969).

a. There are a total of 1,138 residential addresses in Grier Heights. When the address polygons were converted to a grid, it took 9,141 grid cells to represent the residential area.

b. Measured by the local housing authority for violations of minimum housing code. Violations can range from a broken window to lack of structural integrity.

c. Identified by city inspectors who periodically patrol neighborhood streets and record instances of disorder, such as overgrown weeds and grass, abandoned motor vehicles, and trash.

d. Lighting data were collected from a "windshield survey" conducted by officers and planning personnel of the Charlotte-Mecklenburg Police Department. They identified the locations of street lights, and a geographic information systems (GIS) analyst buffered each point using the radius of illumination each light casts, enabling us to identify areas of illumination and pockets of darkness.

e. We had considered using bus routes as an additional variable, based on Brantingham and Brantingham's (1981) literature that in urban areas with public transportation, the awareness space of criminals may be more concentrated on the paths and nodes of public transportation. However, the Grier Heights neighborhood is saturated with bus routes to the extent that most of the neighborhood would fall within a two-block buffer of its bus routes.

f. Because the study neighborhood has organic street blocks of varying lengths rather than a uniform grid pattern, a distance of 500 feet was used to approximate one block. This estimate was based on an average of a sample of streets, which were selected and measured via screen and cursor measurement in the GIS.

g. It is regrettable that the arrest data available for this study do not include juvenile offender home addresses. It is also unfortunate that the data consist of arrestees rather than those convicted of burglary. There were three offender addresses used in the study.

categorized as 1 if there had been a burglary or attempted burglary and 0 if the address was not burglarized during the study period. In the second analysis, we identified those addresses that were repeat victims of burglary and categorized addresses with two or more burglaries or attempted burglaries as 1 and addresses victimized one or fewer times as 0. In both cases, burglary is treated as dichotomous because we are interested in predicting desirable targets rather than the exact number of burglaries. However, there is ample evidence to indicate that the same addresses tend to be burglarized repeatedly (Farrell and Pease 1995; Forrester, Chatterton, and Pease 1988; Sherman, Gartin, and Buerger 1989). Indeed, prior research tells us that once an address has been burglarized, its chances of being burglarized again are four times greater than that of a residence that has not been burglarized (Forrester et al. 1988). We chose two approaches to categorizing the dependent variable to determine whether the model was better at predicting one over the other.

Much of the explanatory variable data described in the previous section were collected through systematic site observations made during the winter and spring of 1995-1996 (ending on May 14, 1996). Because it is likely that many of the environmental conditions were present before the windshield survey, we used a window of data that covered residential burglaries six months prior and six months subsequent to the actual survey date.

It is helpful to describe the general characteristics of the distribution of burglary-related incidents (i.e., burglaries or attempted burglaries) in Grier Heights. There are 1,138 addresses in the neighborhood, and during the study period, 85 addresses (7.5 percent) reported 103 burglary-related incidents. Examining only those addresses that reported a burglary-related incident, 16.5 percent (14) were repeat victims and accounted for 31 percent (32) of the incidents.

ANALYSIS

Our initial unit of analysis was residential address, represented through a layer of polygons. Each of the polygons represented a particular address in the study area.[3] Data about the polygons existed in several GIS feature types. Some of the data attributes were already attached to the polygons, others were point layers, and still others had to be calculated in the grid portion of the analysis. All the variables were converted from vector data format into raster data format during the analysis, thereby converting the unit of analysis to the grid cell.

Before the vector data could be converted into raster format and analyzed using Spatial Analyst, it was necessary to determine what grid cell size to use in the analysis as well as what modeling techniques to employ for representing the variables. The choice of grid cell size is a balancing act between choosing an accurate representation of address polygons of various sizes and maintaining a manageable file size. The optimal grid is the largest cell size that best represents the address polygons; in this case, we used a cell size of 25 feet.

Each variable was then converted from vector to raster format into a dichotomous variable, with 1 equal to presence and 0 equal to absence. The conversion process varied based on the attributes of the variable being converted. Variables that described an attribute of an address that already corresponded to an individual address polygon were converted directly into separate grids. For example, the polygon database contained information on type of land use for each address, so this variable could be immediately transformed into a grid cell layer in which each cell was coded 1 if the address was residential and 0 if it was any other type of land use. This procedure was used to create the *residential land use, housing tenure, vacant, substandard, nuisance violation, dark, corner lot, adjacent to wooded area or vacant lot,* and *proximity to major thoroughfare* grids.

Two variables, proximity to likely offenders and proximity to bus stop, required calculations of distance from a point or points to each address in the neighborhood. The "find distance" function in Spatial Analyst created a grid in which the value of each cell represents the distance from each point(s) to each grid cell. The "map query" function was then used to identify which grid cells met specified criteria that were being used in the calculation of that variable's grid. For example, to develop the bus stop grid, we first used the find distance function. Find distance considers all the bus stops and all the residential parcels and creates a grid in which each grid cell is assigned a value representing the distance from each bus stop to that grid cell. We then used the map query[4] function to select only the grid cells within 330 feet.[5] Those within 330 feet were coded 1 to indicate they were near a bus stop, and all others were coded 0 to indicate they were not.

The procedures outlined above resulted in the creation of a series of grids, one for each variable. At this point, we could have summed the grids and examined the results, but we also wanted to incorporate the effect of characteristics present at one address on nearby addresses. Our reasoning for doing so is that many of the variables that characterize one grid cell may have an effect on neighboring cells, even though the neighboring cells do not share those characteristics. For example, cells adjacent to those with substandard housing may represent more desirable targets than those that are not, even if the adjacent cells are not substandard. By factoring in neighboring cells' characteristics, we can model the effect that desirable targets have on their neighbors.

To model the "fuzzy" effect that each variable has on its surroundings, we created a grid of the focal mean values for each neighborhood of cells. We decided on the size of the cell neighborhood based on the typical lot in Charlotte, which is 50 by 100 feet. Thus, we used a cell neighborhood size of 10 cells (250 feet × 250 feet) so that an average cell neighborhood would include addresses both behind and across the street from the address in question and at least two addresses on either side. Obviously, the number of addresses included in the cell neighborhood varies with the size of the address polygons.

The new value for each cell in a neighborhood of cells is computed based on the mean of the surrounding neighborhood of cells. Figure 1 illustrates the concept of a 10 × 10 neighborhood of cells. We used a focal function to calculate the values for each cell. This approach was chosen because in a focal function calculation, neighborhoods can overlap, and all the cells are processed one cell at a time (ESRI 1998). Thus, the calculation for each cell used all of its neighborhood cells, even if they had previously been used for the calculation of its neighboring cell. Using a 10 × 10 block for calculation of the mean grids, we computed a grid of mean values for each variable and then employed the "map calculator"[6] function to add the grids.

By adding the grids, we produced a sum grid in which the value of each cell represented that cell's opportunity score. By calculating the standard deviations from the mean, we were able to classify the cells into five groups based on their predicted level of opportunity. As seen in Figure 2, a histogram illustrates that the opportunity scores were normal distributed. We then created two maps depicting opportunity surface grids based on standard deviations, one with all burglaries and one with just repeat burglary locations. A comparison of the two maps yielded the results described in the next section.

RESULTS

General Description

As described in the Method section above, each of the predictor variables was combined to create an overall opportunity surface of crime. The results, as represented in Table 2 and Figure 3, display the levels of opportunity across the area based on standard deviations from the mean calculated from opportunity scores.

A visual inspection of the distribution of grid cell opportunity reveals that the three major areas for very high opportunity cells are Heflin Street and Dunn Avenue, Sandlewood Road and Drenan Street, and Billingsley Road and Marvin Road. As an anecdotal test of our model, we questioned

(continued on p. 270)

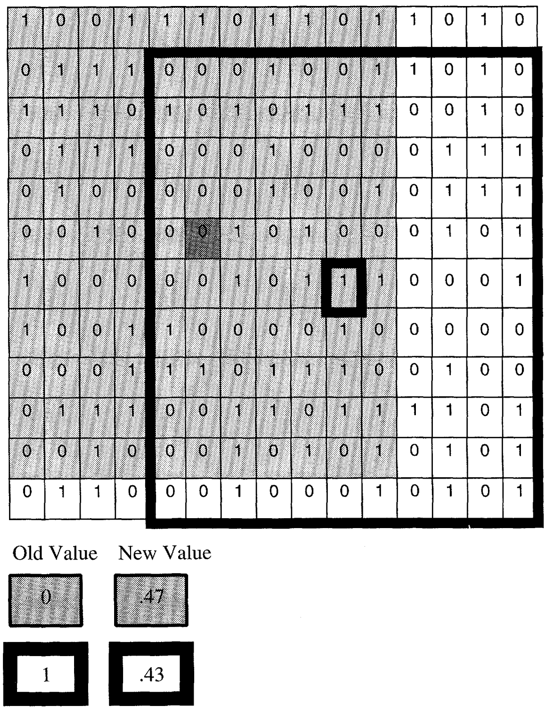

Figure 1: Calculation of Mean Value for Block
NOTE: New value for shaded block = 45 (sum of values)/120 cells. New value for outlined block = 40 (sum of values)/120 cells.

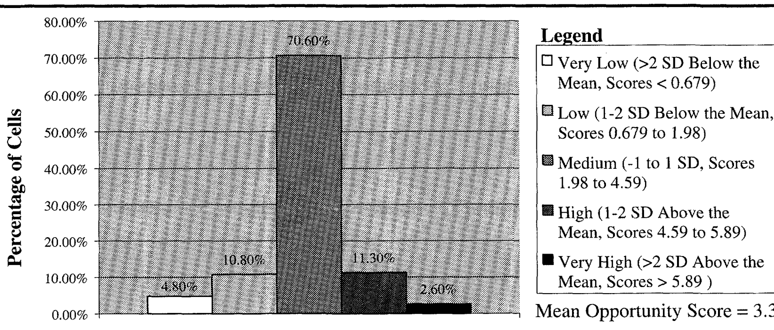

Figure 2: Distribution of Opportunity Scores for Residential Burglary

TABLE 2: Comparison of All Burglary Locations with Repeat Burglary Locations

		All Locations with a Burglary		*Repeat Burglary Locations Only*	
Opportunity Classification	*Standard Deviation of Opportunity Scores*	*Number*	*Percentage*	*Number*	*Percentage*
Very high	Greater than 2 above the mean (>5.887)	3	3.5	1	7.1
High	1-2 above the mean (4.585-5.887)	15	17.7	6	42.9
Medium	1 below to 1 above the mean (1.981-4.585)	62	72.9	7	50
Low	1-2 below the mean (1.981-0.679)	4	4.7	0	0
Very low	Greater than 2 below the mean (<0.679)	1	1.2	0	0
Total		85	100	14	100

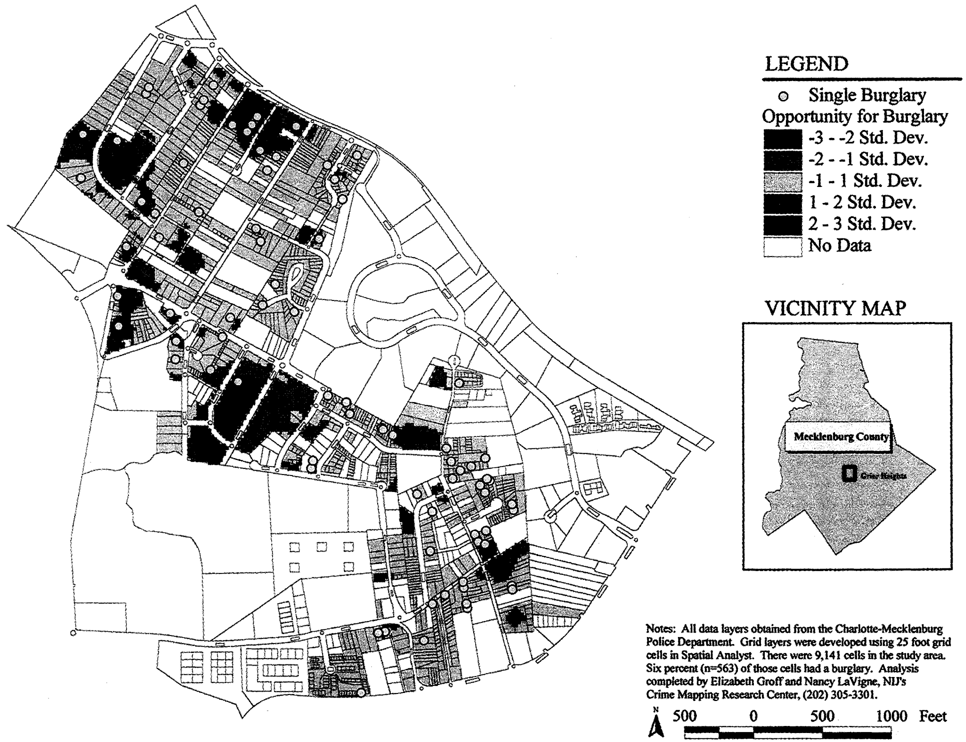

Figure 3: Burglary Locations across the Opportunity Surface Predicted by Model

Charlotte-Mecklenburg Police officers assigned to Grier Heights, who also identified these as the highest crime areas of the neighborhood (personal correspondence, M. Preston and R. Austin, 1996). In addition, the model's identification of low-opportunity areas matched officer observations of two of the most stable areas in the neighborhood in terms of crime (personal correspondence, M. Preston and R. Austin, 1996). One of these stable areas is near the intersection of Fannie Circle and Gene Avenue, and the other surrounds the intersection of Marney Avenue and Stancill Place.

To test empirically the accuracy of the opportunity surface, we plotted the data of known residential burglaries obtained from the Charlotte-Mecklenburg Police Department's incident reports onto the opportunity surface. Figure 3 represents all addresses with at least one residential burglary or attempted burglary, and Figure 4 depicts all addresses with more than one burglary or attempted burglary.

Figure 3 illustrates the overlay of all burglaries on the opportunity surface. Six percent ($n = 563$) of all cells were burglarized over the time period under investigation. An examination of the distribution of burglaries across the opportunity surface indicates that the majority of burglaries (73 percent) fall within plus or minus one standard deviation from the mean, and another 21 percent fall in grid cells from one to three standard deviations above the mean (see Table 2). Thus, it appears that the majority of burglaries occurred in grids with average opportunity or higher. Prediction of the low-opportunity areas is more accurate because only 6 percent of burglaries occurred in areas with opportunity scores greater than two standard deviations below the mean.

An examination of the 14 locations (16.5 percent of all grid cells) that reported more than one burglary during the study period yields more promising results for our model (Table 2, right-hand columns, and Figure 4). All of the repeat burglary locations were in the areas that the model classified as having an average or above-average opportunity score, with 50 percent of burglaries occurring in grid cells from one to three standard deviations above the mean. No burglaries occurred in grid cells classified from one to three standard deviations below the mean. These findings lead us to an exploration of the specific characteristics of the predicted hot and cold areas that might indicate why they had high or low levels of victimization.

Examination of Cold Cells

The strength of the model at predicting areas representing undesirable burglary targets raises a question: namely, what are the characteristics of the lowest-opportunity grid cells that make them less desirable to burglars? An examination of the grid cell values for only the cold cells for which no burglaries occurred (i.e., those for which the model predicted accurately)

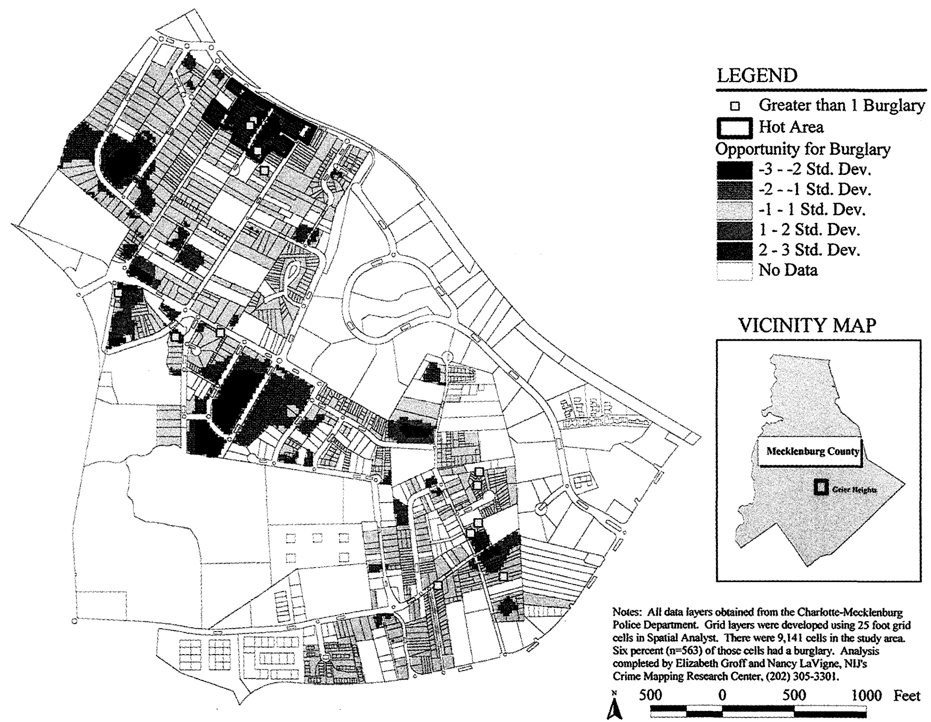

Figure 4: Repeat Burglary Locations across Predicted Opportunity Surface

TABLE 3: Distribution of Variables in Low-Opportunity-Ranked Areas

	Cold Addresses (with no burglary)	
Variable	*Total Number*	*Percentage*
Total addresses	89	100
Housing tenure renter	32	36
Vacant unit	0	0
Substandard housing unit	0	0
Nuisance violations	7	8
No street lighting	7	8
Within proximity to bus stop	33	37
Corner lot	2	2
Adjacent to wooded areas and vacant lots	11	12
Close to major thoroughfare	1	1
Close to likely offenders	17	19

indicates that the vast majority of the cold grid cells did not have any of the environmental characteristics used in the study to indicate desirable offending opportunities (see Table 3). Specifically, all cold grid cells had an absence of substandard housing and vacant units, only two of the grid cells were on corner lots, and just one cell was close to a major thoroughfare. Of the remaining study variables, which included measures of nuisance violations, street lighting, adjacency to a vacant lot, and proximity to a likely offender, at least 80 percent of the grid cells were free of these characteristics. Interestingly, there were two exceptions: housing tenure and proximity to a bus stop. Thirty-six percent of the cold grid cells were renter occupied, and 37 percent were in close proximity to a bus stop. These findings suggest these two variables may not be as important predictors of low-opportunity areas as other variables included in the model. In the case of renter-occupied units, it is possible that such units do not present desirable offending opportunities because they are insulated by the lack of other predictors or by their neighboring units, which are owner occupied. There may also be a "tipping point" or interaction effect by which renter-occupied units alone do not present desirable targets, but they do when combined with some number or combination of other predictors.

Although hot areas were less accurately predicted with our model, it is nonetheless instructive to examine the characteristics of cells for which the model accurately predicted hot areas. For this purpose, we selected one hot area near the corner of Dunn Avenue and Heflin Street on the northern side of the neighborhood. This area was selected for both its concentration of hot grid cells and its high number of known burglaries. In this hot area, more than three-fourths of the addresses were close to a major thoroughfare, close to

TABLE 4: Distribution of Variables in Selected Hot Area

	Hot Addresses: Dunn Avenue and Heflin Street	
Variable	*Total Number*	*Percentage*
Total addresses	79	100
Housing tenure = renter	78	99
Vacant unit	23	29
Substandard housing unit	61	77
Nuisance violations	37	47
No street lighting	13	17
Within proximity to bus stop	69	87
Corner lot	11	14
Adjacent to wooded areas and vacant lots	23	29
Close to major thoroughfare	79	100
Close to likely offenders	79	100

likely offenders, close to a bus stop, and had been cited for substandard housing conditions. Almost half of the addresses in the hot area displayed visual signs of disorder (i.e., nuisance violations), and close to a third were vacant or adjacent to vacant lots/wooded areas. Despite these accurate predictors of burglary, it is noteworthy that neither low street lighting nor occupying a corner lot seem to be associated with burglaries, at least in this study area.

DISCUSSION

The analysis discussed above offered interesting results. The model, a raster-based surface using variables of equal weight, was useful in predicting high-opportunity areas for repeat burglary but did not depict the high-opportunity areas for single burglaries. When it came to predicting low-opportunity areas—those least desirable to burglars—the model performed very well under both single- and repeat-burglary scenarios.

One might question of what practical use the prediction of cold spots would be. Whereas these areas may not be the ones targeted for crime control and prevention efforts, we believe they hold implications for the possibility of spatial displacement in response to interventions in areas adjacent to them. For example, if an intervention was implemented in an area that borders on a cold spot on one side but not on another, extra efforts to prevent displacement could be targeted only at the latter geographic area. Also relevant from a prevention perspective is to take note of those factors that are absent in cold areas. All but two variables used to predict hot areas were essentially absent in cold areas: housing tenure and proximity to a bus stop. The high incidence of renter-occupied housing suggests that these units, when in areas that otherwise have an overall low-opportunity structure for residential burglary, do not present desirable targets for offenders.

The question remains as to why the model was less successful at predicting the very high burglary areas. We know that Grier Heights is a crime-ridden area, and as our figures indicate, burglary incidents are distributed across most of the neighborhood. It is possible that there is a "threshold effect" in operation, whereby once potential criminals find themselves in areas that present adequate opportunities for burglary, one target is as good as the next. Although this runs counter to the rational choice perspective on the micro level, burglars may still be undergoing informal cost-benefit analyses to choose targets, but they are doing so by area rather than target by target. Indeed, ethnographic studies support this finding, demonstrating that even housing units in lower socioeconomic status neighborhoods are targets because burglars recognize that "every place has something worth taking" (Cromwell, Olson, and Avary 1991).

Another problem with the study area chosen for this analysis is that it is relatively small geographically. It is likely that applying this model to an entire city, although data intensive, would yield more significant results due to the variation in criminal opportunities we would expect to find in a larger, more heterogeneous area.

Both underreporting of burglaries by victims and underrecording of burglary incidents by police officers are related factors that may have affected the ability of the model to predict hot areas because not all burglary occurrences were reflected in the data. In high crime areas, victims tend to report fewer crimes. Consequently, official data sources such as police reports do not accurately reflect the scope of victimization, and this is particularly true for repeat victims (Biderman and Reiss 1967; Farrell and Pease 1995; National Board for Crime Prevention 1994; Shover 1991). In addition, burglaries in poor areas are recorded by police officers significantly fewer times than those in higher income neighborhoods, thus altering the pattern of burglaries of the neighborhood (Warner 1997). Underreporting of burglaries is particularly devastating in a micro-level study such as ours.

It is also possible that the model did not predict hot areas well because the independent variables were all weighted equally. Future research employing a more complex method may produce more accurate findings with regard to high-opportunity areas. For instance, the use of logistic regression analysis with the inclusion of a spatial lag, for example, may reveal that some variables are more significant and should be weighted accordingly, whereas other variables should be removed from the model. Another possibility would be to employ discriminant analysis because it indicates which combination of characteristics best discriminates between addresses that were victimized and those that were not. Employing a more sophisticated model will make the technique less accessible to the average law enforcement agency. However, refinement of the model will increase both its predictive ability and our understanding of the underlying processes at work, both of which have implications for targeting and evaluating prevention initiatives in the field.

One last word about applicability and ease of use of the technique in crime analysis units: This research was conducted using Spatial Analyst 1.0, a software package that requires significant manipulation of data layers by the analyst to complete such an analysis. A more recent version of the software allows models to be defined and then run in the equivalent of a "batch" mode, essentially automating the model process. Specific variables and weighting schemes can be easily changed without redoing the entire model and then rerun without human intervention. The savings in time gained by the new software will make the use of raster-based modeling feasible for time-pressed crime analysts.

Because crime analysts will now be able to conduct this type of analysis in a timely fashion, it can be used with utility in law enforcement agencies. Advantages to raster-based modeling revolve around ease of visualizing a complex process and in decision support. The maps produced in a raster analysis enable members of law enforcement to clearly identify areas that have a high potential to experience certain types of crime without requiring them to cull through layers and layers of relatively generic information (e.g., maps of housing tenure, distance to bus stop). Consequently, raster analysis has the potential to serve as a decision support tool, providing a single answer instead of a myriad of maps of distributions from which the officer or crime analyst must deduce information pertinent to the question at hand. In fact, the promise of GIS and, specifically, raster-based analyses such as the one presented in this article is that it has the potential to take the visual display of data from the descriptive realm to the inferential realm.

NOTES

1. The National Institute of Justice has funded a number of grants to develop such predictive models, drawing on spatial regression analysis, environmental modeling, neural network analysis, and other methods and having the capability of being displayed within a geographic information system (GIS) (www.ojp.usdoj.gov/cmrc).

2. Environmental Systems Research Incorporated (ESRI) is based in Redlands, California, and developed both ArcView and Spatial Analyst.

3. Address polygons were created from a layer of parcel polygons that was converted from a computer aided design (CAD) file and projected into the State Plane coordinate system (Nad 83, Feet, North Carolina). In Charlotte, parcels are the unit of land ownership, but one parcel can

have many addresses (e.g., a parcel with a duplex on it would have two addresses). Thus, we split up each parcel into as many polygons as there were addresses on the parcel; each polygon then represented one address but still contained all the descriptive information from the parent parcel (e.g., owner name, owner address).

4. The map query function in ArcView's Spatial Analyst extension allows the user to select grid cells that meet specific criteria through the use of an expression.

5. Because of the density of bus stops in the neighborhood, a one-quarter-mile (1,320 feet) buffer selected all the residential units. Halving the buffer to 660 feet still selected 90 percent of the residential addresses, so the distance was halved yet again to 330 feet. The 330-foot buffer distance selected a smaller proportion of the units and was used in the analysis.

6. The map calculator is a utility in Spatial Analyst that enables the user to perform algebraic functions on one or more grids.

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