GEOGRAPHIC INFORMATION SYSTEMS AND CRIME ANALYSIS IN BALTIMORE COUNTY, MARYLAND

by

Philip R. Canter
Baltimore County Police Department

Abstract: *Analytic mapping and geographic databases are being increasingly recognized by police departments as an important tool in crime analysis, crime prevention and program evaluation. Improvements in technology, reasonably priced computer-based geographic information systems (GISs), and the availability of geographic data sources make it possible for law enforcement agencies to use analytic mapping. Police departments using automated mapping systems largely rely on attribute data associated with point locations to produce computer pin maps based on a variety or combination of crime event features. GISs can be used as a tool to identify factors contributing to crime, and thus allow police to proactively respond to the situations before they become problematic. This article will explore the use and possibilities of GIS by Baltimore County Police in describing and analyzing crime activity. Examples are included that demonstrate the potential of GIS in analyzing crime, developing interdiction strategies, and evaluating the effectiveness of prevention strategies. As this technology gains greater acceptance and use within police departments, it will become clear that the ability to produce automated pin maps is only one of many possible applications. Ultimately, GIS should be viewed as a tool for which police analysts could obtain a better understanding of criminal activity from a geographic perspective.*

Address correspondence to: Philip R. Canter, Baltimore County Police Department, 400 Kenilworth Drive, Towson, MD 21286.

CRIME ANALYSIS IN BALTIMORE COUNTY, MARYLAND

Baltimore County Police Department's Crime Analysis Unit

The primary objective of Baltimore County's crime analysis unit is to provide information that can make the police department more efficient in carrying out its universal mission: to prevent and suppress crime. Crime analysis influences policy, helps justify budget requests, and assists in identifying or defining a problem for further study. While the purpose of crime analysis in some police agencies can vary, it is generally recognized in Baltimore County that competent analysis provides important input to decision makers.

Baltimore County Police Department created its Crime Analysis Unit in the late 1970s during a time of rapidly escalating crime. The unit's mission was to identify crime patterns (cluster analysis) and trends (time series), relate known suspects to crime incidents (linkage analysis), provide information needed to deploy police resources in response to an identified crime problem, and evaluate the effectiveness of crime prevention/suppression strategies. Since its inception, Baltimore County's Crime Analysis Unit has strongly emphasized case and suspect information.

Data are the foundation of any crime analysis unit. Analysts in Baltimore County developed a special coding form called the Crime Analysis Worksheet to collect information needed to identify attributes associated with criminal incidents. The Crime Analysis Worksheet contains information about the crime such as modus operandi, location of crime, actions taken by an offender to commit the crime, property taken, and suspect/vehicle information. The investigating officer circles the appropriate response to each category on the worksheet, and then forwards along with a copy of the offense report to the Crime Analysis Unit. Police officers are required under Rules and Regulations to complete a Crime Analysis Worksheet for any robbery or burglary in Baltimore County. The crime analysts initially focused on robberies and burglaries because it was believed that either crime would be responsive to a police strategy such as directed patrol, tactical deployment, or surveillance. Eventually the Crime Analysis Worksheet was converted to a bubble scan format, allowing analysts in Baltimore County to add motor vehicle theft and drugs to the crimes analyzed.

Once a Crime Analysis Worksheet is received by an analyst, information contained on the form is checked against police reports associated with the incident and then entered into a computer for subsequent analysis. Because the department's first computer system — an IBM System 3 — was equivalent to a low-end 8088 microcomputer system, the amount of information and type of analyses was limited to pre-designed summary statistical reports with some cross-tabulation of pre-selected categories. Eventually crime analysts were able to use statistical software, spreadsheets, and database management systems as advancements occurred in microcomputers and software.

One method used by crime analysts to determine locations containing a high concentration of incidents is a pin map. Crime locations, usually represented by a pin, are placed on a map containing all of the streets for an area of interest such as a police precinct or a municipality. The size and area of the map used for pin mapping will depend on its scale. Map scale relates and adjusts a mapped distance to the actual geographical distance. The map scale is important because it will determine the area of study, and the relationship between a particular point location such as a street robbery to other geographic features such as a bus stop or shopping center. The map scale also influences an analyst's ability to determine through visual inspection whether the areal distribution of crime constitutes an unusually high concentration of points.

Police analysts in Baltimore County originally used 2,000 scale base maps developed by the Maryland State Highway Administration for their pin mapping. Analysts needed to assemble and join twelve 2,000 scale maps to cover the entire 610-square-mile area of Baltimore County. Each map of the County required 70 square feet of wall space. Any other geographic features of interest, such as police reporting areas, precincts or posts, were drawn by analysts on each countywide map. Since police reporting areas are subdivided police precincts delimited by streets or other geographic features such as railroad tracks or power lines, it was important that the base maps used for pin mapping be continuously updated to reflect changes in land use and development. Consequently, paper base maps were constantly being printed and assembled by police analysts. The process of continually updating these maps was labor intensive given that there are over 1,200 reporting areas in Baltimore County.

Pin maps can be useful in displaying the location of crime for a large geographic area such as a county or police precinct. Some Baltimore County crime analysts have also maintained that the act of reading a report and physically placing a pin on a map helps them to retain information about the crime. As the number of crimes increased in Baltimore County, however, the amount of effort required to manually maintain pin maps became problematic. The ability to accurately place a pin on a map that represented the actual crime location required a considerable amount of effort by the analyst. Obvious limitations associated with manual pin mapping also compromised the geographic accuracy associated with crime locations. In addition, the amount of information associated with a case and represented by a pushpin was limited to a few characteristics, like time of day or modus operandi. Consequently, there was a possibility that an analyst could miss an active crime pattern. Furthermore, the geographic location of an incident represented by a pin on a map is not quantifiable, so analysts were prevented from testing hypotheses about the spatial distribution of crime. Finally, the base maps needed to be constantly updated as new roads or other geographic features in Baltimore County changed over time. It became apparent that county police needed to use a geographic information system to assist in the mapping and analysis of crime.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems (GISs) use computers to represent and analyze spatially related phenomenon. All GISs have two functions: (1) to display maps or geographic features such as crime locations (points), streams (lines), or census tracts (polygons); and (2) to use a database manager that organizes and relates attribute data to various map features. A GIS uses a digital map database to link spatial data to descriptive information.

Several types of matching algorithms enable a GIS to link and maintain spatial relationships between geographic and descriptive information. The ability to link and maintain spatial relationships between data sets defines a GIS. As an example, suppose two data sets exist for a city: number of robberies by reporting area, and population by reporting area. These two data sets can be either mapped individually or combined to show a robbery rate. Now increase the number of data sets from two to six. The number of different map combinations increases to over 60. Increase the number of data sets to 10, and you have over 1,000 possible combinations.

A GIS can combine data using either spatial or tabular file attributes. The ability to combine data collected for different boundary layers addresses a problem analysts often confront: examining relevant data collected by other agencies which, for a variety of reasons, are unable or incapable of matching police geography. One recent example in Baltimore County involved the need for various local government agencies participating in a community conservation program to identify deteriorating urban communities targeted for intervention strategies. Each county agency used either its own geographic unit such as a school district, or census geography such as a tract to collect data used to identify deteriorating urban communities. The different boundary layers used by various county agencies, including reporting areas (police), census tracts (planning), and school districts (education), had to be combined to form a composite layer showing the location of deteriorating communities. Digital map files representing the various boundary layers were already available and used in a countywide GIS, so combining information associated with the different geographic boundaries to form a composite layer was fairly routine. While one has to be cautious about making inferences for small areas based on statistics collected for larger, overlapping geographic areas, the fact remains that most government agencies collect data at different geographic levels and scale. The ability to combine information associated with different geographic boundaries, a process sometimes referred to as "fuzzy" matching, is a powerful descriptive tool.

Geographic Information Systems and Baltimore County Police Department

The location of a crime is an important attribute feature, and is included along with law, offender, and target as a dimension of a criminal event (Brantingham and Brantingham, 1991) . Crime location, and any other geographic information associated with a criminal event, can provide clues about the identity of suspects, assist in the design of prevention or apprehension strategies, aid in the evaluation of programs, and help gain a better understanding of environmental factors that may be associated with crime.

Analysts interested in identifying areas containing a high concentration of crime need to know the location of incidents. As noted earlier, there are several issues associated with manual pin maps that limit their value as an analytical tool. Baltimore County police analysts spent a large amount of time determining the placement of pushpins representing an offense location. As caseload increased analysts became more interested in the number of incidents by reporting area, and not necessarily by point location. Yet, there was a recognition that the point locations, particularly relative to other map features, were an important part of crime analysis. There was a strong need, therefore, to determine the accurate placement of incident locations in a cost-effective and efficient manner.

By the mid-1980s there were several events that moved the Baltimore County Crime Analysis Unit into a microcomputer-based GIS environment. These events included a centralized records management system that allowed crime analysts to download significant amounts of information on crime, such as an incident location represented by a street address and the last known home address of an offender associated with a criminal incident. Other events involved: improvements in microcomputer processing and storage systems needed to use and manipulate large database files; the availability of microcomputer software needed to synthesize and analyze large quantities of data; and cost reductions for computers and peripheral equipment such as printers and plotters. In addition, the redesign of Baltimore County's communication system used for dispatching calls received by the 911 center to police, fire, and emergency medical services was particularly important in influencing Baltimore County police to use a GIS.

Baltimore County's communication system had a number of problems, including limited voice transmission and inaccurate geographic reference tables needed to associate call locations to a dispatch plan. Limited voice transmission would be addressed by broadcasting over a new 800 Mhz system paid for by a voter-approved bond referendum. A problem remained with the geographic reference tables, collectively called a geofile, because attempts to internally maintain these files to reflect changes in land use and new development were too numerous and technically challenging given the equipment and resources available at the time. It was recognized that improvements to the 911 communication system provided an excellent opportunity to improve the geofile used by the computer-aided dispatch (CAD) system.

It was known that the Baltimore Region Metropolitan Planning Organization (MPO) had been maintaining and updating a digital map file for Baltimore County based on the 1980 census GBF/DME file. It became necessary to convince county government to use some of the bond funding for updating or replacing the 911 CAD geofile. This was not an easy task since project costs had already exceeded budgeted amounts. Furthermore, individuals responsible for maintaining the 911 CAD geofile believed that any problems with the file were being exaggerated.

To demonstrate that problems existed in the 911 geofile, a GIS was used to construct a map showing discrepancies between the 911 CAD geofile and the MPO digital map file. The map convincingly showed that streets in the 911 geofile had inaccurate address ranges, and were in many cases assigned to the wrong police reporting area. The map also demonstrated the utility of a GIS. As a result, the MPO was contracted to update the 911 CAD geofile, and to supply quarterly updates reflecting changes in land use and street topology.

One issue associated with digital map files concerns their geographic accuracy; that is, how closely geographic features such as roads or streams represented as x,y coordinates in a digital map file relate to the earth's surface. Since the geofile provided by the MPO was to be used for geographically tracking police cars via an automated vehicle locator (AVL) system, it was important that the file be geographically accurate. A third party vendor, ETAK, was subsequently contracted to adjust and calibrate the digital map files so that they were positionally accurate to within 50 feet. In summary, Baltimore County was not only able to improve the accuracy of its 911/CAD geofile, but was also able to obtain geographically accurate digital map files that could be used by a GSI. The digital map files provided by the MPO not only included maps of all county streets, but also various boundary files such as police reporting areas, zip codes, Census tracts, Census-designated places, Census block groups, and transportation zones. The digital map files and accompanying boundary layers were subsequently exported for use by Maplnfo, a GIS selected by Baltimore County police for computer mapping.

The Baltimore County Police Department was the first county agency to use a microcomputer-based GIS. To demonstrate the potential of computer mapping within the department, in conjunction with the MPO police analysts used Maplnfo to geocode drug arrest locations coded by drug type and action (sales/possession). The same demonstration maps were included in an application to the Bureau of Justice Assistance's Byrne Memorial Grant Program. The proposal was funded and the department was able to purchase additional hardware and software needed to track and identify drug markets in Baltimore County.

During this time, a number of other county agencies were actively exploring the use of microcomputer-based GISs. With the coordination of Baltimore County's Office of Planning and Zoning, several other county agencies purchased Maplnfo for computer mapping. These county agencies entered into a site license agreement with the

MPO to provide quarterly updates to Maplnfo mapfiles. The site license purchase agreement allowed county agencies to obtain updated mapfiles at a reasonable cost. It also ensured that geographically coded data used by other agencies were based on the same coordinate system.

Most Baltimore County agencies are now using Maplnfo for microcomputer mapping. A County Maplnfo Users Group was formed to provide training and assistance in mapping applications. In addition, a newsletter called "Maplnformation" is produced quarterly for county agencies using Maplnfo. The newsletter contains articles contributed by user group members, as well as suggestions on using computer mapping applications. The introduction of a countywide microcomputer-based GIS has prepared many agencies for an upcoming migration to a wide-area GIS network. Using a RISC-based GIS/RDBMS called Arclnf/Arclnfo and Oracle respectively, county agencies will eventually be able to access and process most geographic information maintained at one location.

Applications of Geographic Information Systems by Baltimore County Police Analysts

GISs have three broad applications: (1) forward data mapping; (2) backward data mapping; and (3) interactive data modeling (Levine and Landis, 1989). The design and respective cost of a GIS will depend on a system's ability to perform each of the three applications. A powerful GIS system will be capable of performing all three operations, while a lower-cost GIS may be strong in forward and backward data mapping, but less capable of performing interactive data modeling. A police department will need to determine how the system is to be used before making a decision as to which system to purchase. For this reason, it is recommended that an agency perform a comprehensive review of user needs and expectations prior to purchasing a GIS.

Forward Data Mapping

A common GIS application involves the ability to map point locations, and to shade areas reflecting the presence and intensity of a variable. Both applications are referred to as "forward data mapping." Forward data mapping is used to map attributes contained in the database files that are linked by a GIS to a geographic location. The process of forward data mapping is analogous to descriptive mapping, since some type of geographic information and its respective attributes are being described on a map. Forward data mapping involving point locations is also referred to as automated pin mapping because maps closely resemble the types of maps used by police analysts for pin mapping. For this reason, most police agencies use a GIS almost exclusively for their forward data-mapping abilities.

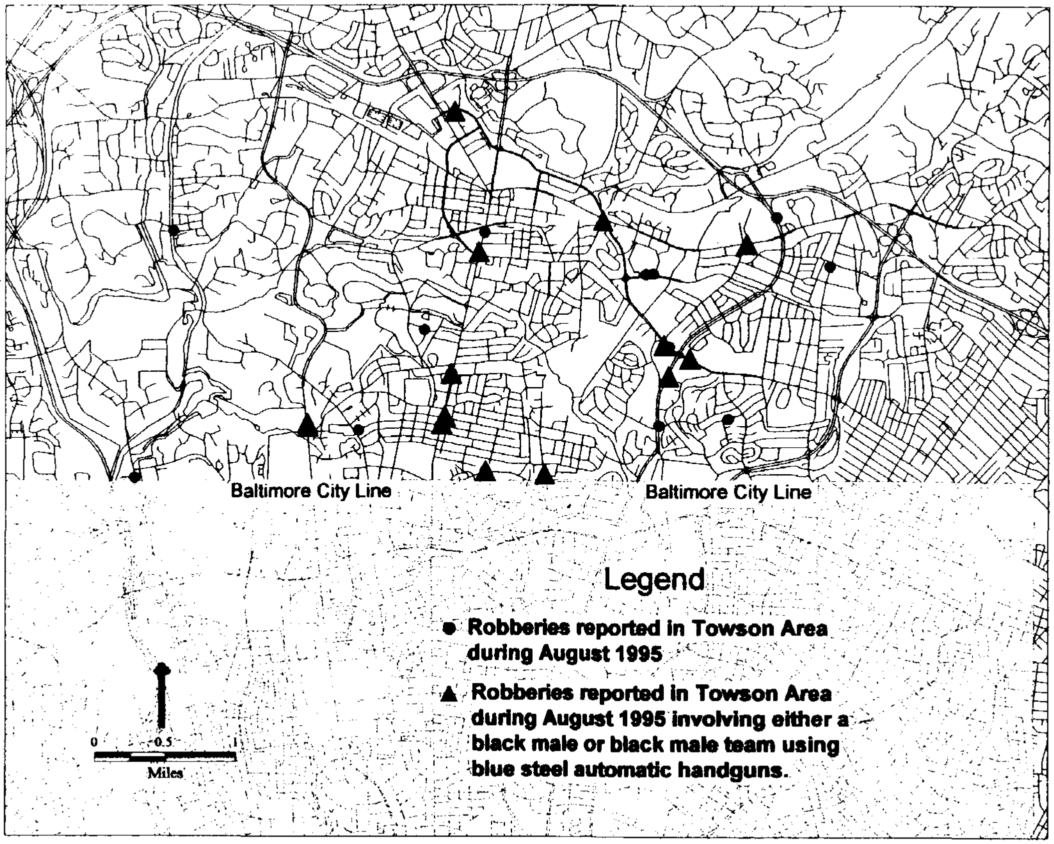
Most of the maps produced by crime analysts in Baltimore County, particularly those presented to the community or to police commanders, involve forward data mapping. The maps produced by police analysts show the location of crime represented by one or more case attributes. For example, a robbery location will appear as a triangle, and color coded according to type of location (convenience store, bank, street, etc.). Color intensities associated with each robbery location will vary to represent day or night offenses. Police analysts also have greater flexibility in manipulating mapped data through database commands that select and map information based on user-provided criteria.

The ability to relate attribute data to a geographic location is useful in determining when and where to deploy police resources in response to a particular crime problem. Patrol officers have commented that these types of descriptive maps have been helpful in problem solving and for directed patrol. Police analysts also use forward data mapping to determine the effects that a particular strategy, such as increased police visibility in a community, may have on the number and location of crimes observed over time.

Figure 1 is an example of forward data mapping. Police analysts were confronted with an increase in robberies reported in the Towson area of central Baltimore County during August 1995. An examination of the attributes associated with these robbery cases revealed that a large number involved either a black male or pair of black males using a blue steel automatic handgun. Most of these cases occurred along major arterials, and were close to the city-county line. Based on the location of these robberies, it appeared that major arterials were being used as escape routes and that the offenders were destined for the city. This is usually enough information to: (1) identify the type of problem occurring, (2) determine which locations were victimized by the same offenders, and (3) develop a tactical strategy, in this case resource deployment for use in areas likely to contain target locations and escape routes.

Forward data mapping also allows an analyst to assign attributes associated with a file record and represented geographically by an x,y coordinate pair to a polygon like zip code or Census tract. Once attri-

Figure 1: Robberies Reported in the Towson Area August, 1995



Note: Shows how forward data mapping is used to identify attributes associated with robbery cases in Baltimore County.

butes are associated to a polygon they can be further represented on a map by a color or thematic pattern. For example, communities experiencing a high number of residential burglaries may appear as a bright color compared to a community experiencing a fewer number of cases. A GIS could also use a color corresponding to a range of counts such as all communities containing between 5 and 10 residential burglaries. Police analysts in Baltimore County usually use thematic maps to display information based on a large number of records, such as burglaries over a one-year period or average police response times calculated from over 300,000 CAD data records. While the tactical value of thematic boundary maps may be limited, these types of maps are useful in quickly conveying the frequency and intensity of crime to police precinct commanders and the public.

The ability of a GIS to perform forward data mapping is the most basic of the three applications. Yet, the ability to quickly and accurately show point locations and any attribute data associated with an incident using thematic mapping is a tremendous benefit to a police department. Since computers are being used to manipulate digital data in a computer mapping environment, the analyst can easily instruct a GIS to display information based on pre-determined criteria. The analyst is still required, however, to make conclusions about the information being displayed, and any interpretations will be based on the analyst's subjective judgment.

Forward data mapping will allow an analyst to display all robbery locations on a computer map, but it will not identify for the analyst areas constituting a high concentration of incidents. The analyst will intuitively identify areas containing a high number of robberies based on a visual inspection of the map in a manner similar to that used with pin maps. Nevertheless, the obvious difference between manual pin mapping and a GIS from a forward data mapping perspective includes: improved accuracy in identifying the location of incidents such as crime; the ability to associate and display multiple attributes to any given incident location; the ability to quickly display information using a variety of medium (such as acetate transparencies for overheads, different-size paper, or a computer screen); the ability to display mapped information at different scales; and the reduced time and concomitant reduction in operating costs resulting from having a computer rather than an analyst construct a map.

Backward Data Mapping

Backward data mapping differs primarily from forward data mapping in that selection criteria used to construct a map are based on geographic, rather than tabular, information. In forward data mapping, an analyst will rely on the attribute information to determine how incidents are to be displayed. In backward data mapping, an analyst will have a GIS display information based on the relationship between an incident's location and geography. An analyst, for example, may believe that a high concentration of robberies are determined by incidents located within one half-mile of one other. The GIS would first determine the geographic location of each robbery, and then compute the distance from one robbery location to all other robbery locations. After this operation is performed for all such locations, a map would display only those robbery cases whose closest neighboring robbery location was within a half-mile. The result would be a map displaying a group of cases constituting a high concentration of robberies based on the distance criteria provided by an analyst.

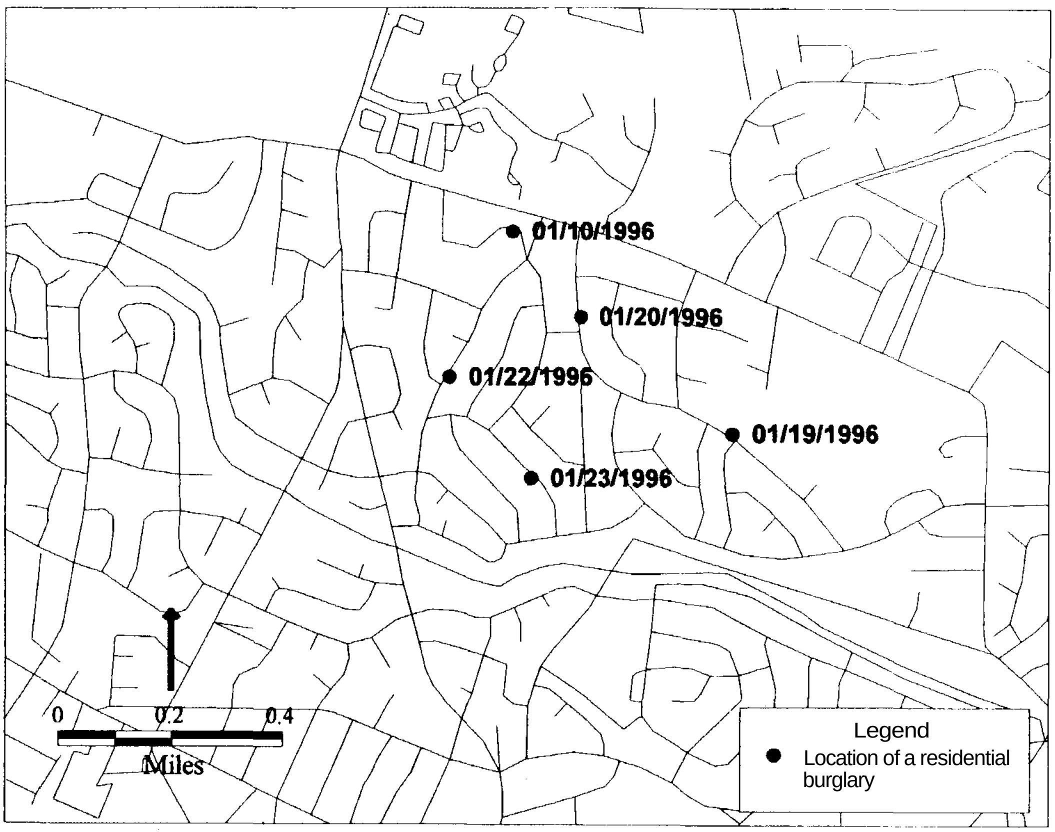
As in forward data mapping, points representing discrete crime locations can be aggregated to a polygon and then thematically mapped. In backward data mapping, a GIS can be used to determine the size of each polygon such as acres or square miles to compute a crime density for each polygon. One polygon, for example, may have more incidents than a neighboring polygon, but it also may be twice as large in land area. A crime density map would allow an analyst to consider the effect a polygon's size may have on the number of incidents. Polygons with small areas and a higher number of incidents may require more attention than a larger polygon with the same number of incidents.

Backward data mapping is the first step in gaining a better understanding of the relationship between crime and geography. The ability to analyze data is enhanced in two ways: first, by associating a map feature such as a road, transit station, or school to an incident location; and second, to relate incident locations to a geographic component, such as longitude and latitude, size, or distance. Rather than relying largely on nominally scaled attribute data, analysts can test hypotheses based on ratio-scaled data such as distance. Backward data mapping is used for spatial analysis such as cluster analysis, quadrat analysis, or nearest neighbor analysis. For this reason, backward data mapping is needed to perform analytical mapping. Backward data mapping also introduces a proactive component to crime analysis by enabling an analyst, for example, to develop models based on relationships between crime and census information; or by marketing crime prevention information to households located in potentially criminally active communities.

Figure 2 shows the distribution of residential burglary incidents occurring within a community located in northwest Baltimore County. Police analysts noted that these cases were occurring within a relatively short time period, involved a particular modus operandi, and were located within close proximity of each other. Analysts concluded that these cases probably involved one or more suspects working together, and that the pattern would likely continue if left unabated. This is an example of how forward data mapping is used to subjectively identify high-crime areas.

Police analysts were interested in using an auto-dialing system to contact and alert households in this community about the burglary problem, and in providing advice to households as to how to prevent their homes from being victimized. A GIS was used to reduce the list of all households in Baltimore County with published phone numbers to only those located within the zip code containing the burglaries. As an example of backward data mapping, police analysts used a GIS to extract published phone numbers for households located within the criminally active area shown in Figure 3.

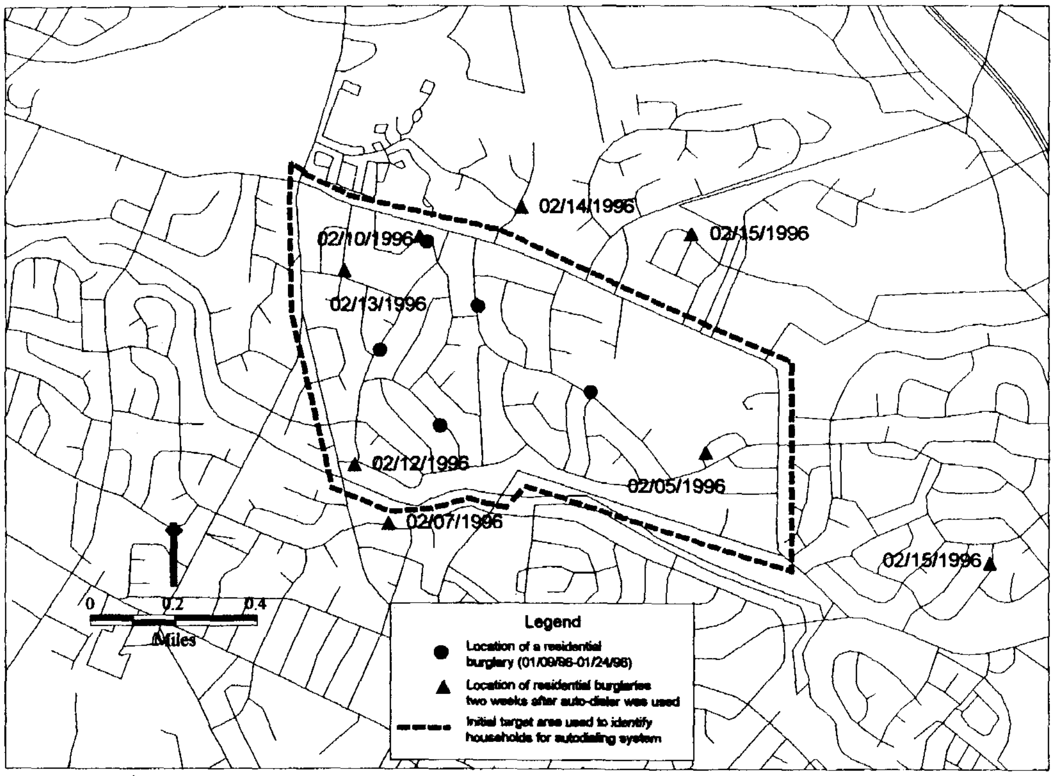
Figure 2: Residential Burglary Cases in Randallstown Community



Note: Distribution of residential burglary incidents occurring within a community located in northwest Baltimore County. Police analysts noted these burglaries probably involved one or more suspects working together because the cases were similar.

Figure 3 shows the location of burglaries occurring after the auto-dialing system was used. The additional burglary cases are largely occurring outside of the initial target area, and appear to have been displaced possibly as a result of the auto dialer. At the time, it was

Figure 3: Residential Burglary Cases Before and After Autodialing



Note: Distribution of residential burglary incidents after the autodialing system was used (02/02/96-02/03/96). Note that the additional burglary cases are largely occurring outside of the initial target area, possible due to a displacement effect.

not known whether this displacement occurred as a result of target hardening, increased vigilance by the community, increased police presence, or the burglary suspect being alerted by the auto dialer because he or she lived within the community. In response to the apparent displacement of burglaries, analysts redefined the target community by expanding the area delimited by a new polygon.

Additional studies of similar situations and applications will determine whether decisions used to define the target community for an auto dialer strategy are accurate. At this time, preliminary findings suggest that some displacement of crime is occurring after a community is targeted by an auto dialer message. It is possible that displacement may be an anticipated reaction by the offender, and that surveillance should be concentrated in areas contiguous to an auto-dialer target community during and immediately after the initial contact period. Most recently, police analysts in anticipating a possible displacement of crime resulting from use of the auto dialer system expanded a target area to include neighboring communities not yet impacted by a residential burglary problem. In the process, one of the people contacted by the auto dialer who had resided in one of the neighboring communities called 911 when noticing two "suspicious" individuals walking down the street. These two individuals were attempting to burglarize a residence in the neighborhood when caught by police.

Interactive Data Modeling

Interactive data modeling involves using a GIS to predict or simulate some phenomenon such as crime. Once models are developed, a GIS can be used to vary and assess conditions influencing expected outcomes. Analysts may have a GIS estimate response times as police post sizes change, or a GIS may be used to determine the number and types of calls for police service given changes in an area's land use. The ability to test and evaluate different simulations can have a significant influence on police operations and policy. Determining, for example, relationships between police response times and the size of a post could influence the number of patrol cars put into service during a shift. Alternatively, changes in land use due to subdivision activity and the concomitant increase in demand for police service may justify a developer impact fee. It is the ability to perform interactive data modeling that makes a GIS such a powerful tool.

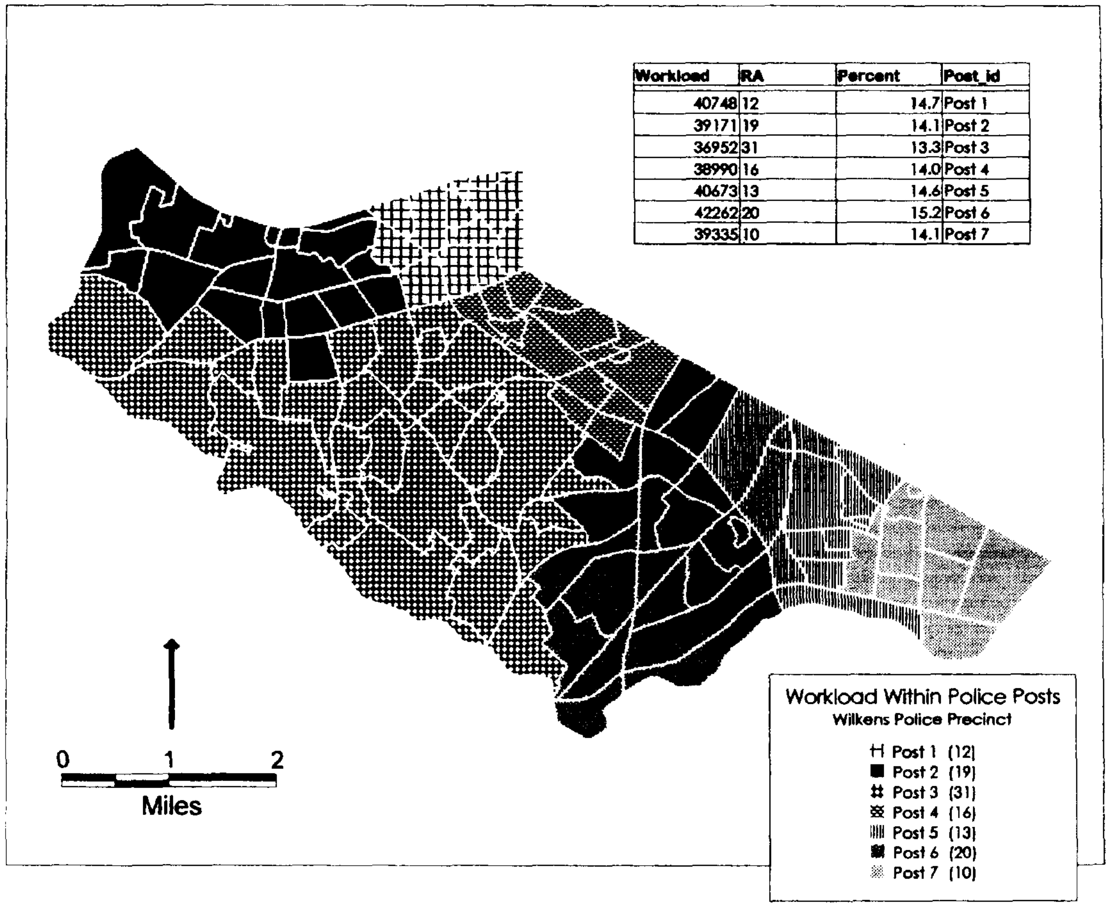
Figure 4 is an example of how police analysts in Baltimore County use interactive data modeling to test the effects different boundary realignments have on balancing work load within police posts. Each call for police service is weighted by call type or workload unit, with calls involving a serious offense such as a violent crime assigned a higher value or weight compared to a less serious offense. Weights assigned to each call-for-service record are subsequently summed by reporting area, and then further aggregated into a fixed number of posts for each eight-hour shift. The objective is to balance work load among posts within each precinct, while maintaining adequate response time.

The precinct shown in Figure 4 is Wilkens, located on the southwest side of Baltimore County. There are a total of seven posts or beats assigned to the Wilkens precinct during the midnight shift. Analysts use a redistricting method in Maplnfo to create police posts by aggregating a reporting area's work load to form seven districts. Since there are seven posts during this shift, each post should contain approximately 14% of the precinct's total work load. Initially the precinct is considered as one large post containing 100% of the work load equal to 278,131 units. Analysts start by aggregating reporting areas and their respective work load to form the first post. As the first post is being created, the percentage assigned to the first district is reduced by the amount added to the first post. This process continues until all seven posts have been created. Analysts use interactive modeling to add or subtract reporting areas and their respective work load to balance call types among the entire police precinct, while at the same time considering the effect these changes may have on police service to the community.

Most of the interactive data modeling performed by a GIS has occurred in the physical sciences and urban systems. Examples include environmental impact assessments, network modeling, Universal Soil Loss Model, hydrologic models, and land-use suitability modeling. There is a significant amount of interest in interactive data modeling for the social sciences, including the ability to geographically predict crime.

The spatial distribution of crime has been extensively studied over the decades, particularly in respect to either the socioeconomic conditions of neighborhoods in which the criminal lives or a crime occurs (Bursik, 1988; Harries, 1974; Shaw and McKay, 1969). Crime as it relates to the built environment has also received considerable attention, notably through the works of C.R. Jeffery (1971) and Oscar Newman (1972). The development of interactive models to geographically predict crime will likely be influenced by social disorder theories, which use socioeconomic conditions as explanatory factors, combined with information on the environment in which crime occurs. Socioeconomic data is readily available, and the ability to link it to crime and/or arrest locations requires a standard matching procedure used by all GISs. Data on the built environment is routinely collected and used as part of a comprehensive GIS.

Figure 4: Police Posts Based on Workload Assignments by Reporting Area



Workload	RA	Percent	Post_id
40748	12	14.7	Post 1
39171	19	14.1	Post 2
36952	31	13.3	Post 3
38990	16	14.0	Post 4
40673	13	14.6	Post 5
42262	20	15.2	Post 6
39335	10	14.1	Post 7

Note: Police use interactive data modeling to test the effects different boundary alignments have on balancing workload within posts. Table at upper right shows Post 1 consists of 12 reporting areas totaling 40,748 workload units or 14.7% of the precinct's workload.

While ecological data allude to important social issues such as the possible effects of poverty and unemployment on crime, the problem of spatial contiguity and spatial scale that can influence the outcome of statistical tests cannot be ignored. These problems are further complicated by variant factors like opportunity, behavior, and motivation that influence the occurrence of crime. Interactive data modeling based on tangible variables pertaining to land use or the built environment, in combination with information on an area's socioeconomic-demographic status, will provide a better understanding of crime. Police analysts will eventually be able to: describe what impact land use changes may have on demand for police service in economically depressed areas; determine why some locations are repeatedly victimized; or study the relationship between features such as transit stops or public housing and crime. As analysts gain additional experience with GIS, the opportunity to develop and refine predictive models will increase.

Using Geographic Information Systems for the Spatial Analysis of Crime

Police analysts in Baltimore County, by studying the geographic and temporal dimensions of crime, can gain a better understanding of the environmental factors that may be influencing criminal behavior. Analysts in Baltimore County use information obtained from the spatial analysis of crime to: identify areas that may likely be targeted by an offender; determine whether common attributes exist among a group of reported cases; explore relationships between crime and other geographic features such as land use and the built environment; investigate relationships between criminal residence and ecological data; and study the movement of offenders to predict the location of future targets and to establish interdiction points along escape routes. Police analysts are particularly interested in identifying crime patterns and determining whether these patterns are randomly distributed due to chance, or if there is a tendency for a set of cases to statistically group or cluster. Once an analyst identifies a spatial cluster, information is disseminated to patrol and specialized units for subsequent action.

Spatial Clustering

Police analysts in Baltimore County continually monitor the geographic distribution of crime for the purpose of identifying high-crime areas or "hot spots." A high-crime area is defined by three criteria:

crime frequency, geography and time. These areas contain at least two criminal incidents of the same crime type. Sometimes the crimes have similar characteristics, such as modus operandi or type of weapon, suggesting one or more offenders working together may be responsible for the pattern; other times the only similar characteristic associated with a crime pattern may be the crime type. A high crime activity area is usually small in size, but may become larger the longer a problem continues. In addition, a high-crime area is usually identified as such based on the number of offenses reported over the most recent one- to two-week period. Once a high-crime area is identified, the analyst will continue to monitor the pattern over time until it abates. In some situations, high-crime areas in Baltimore County have continued for several weeks.

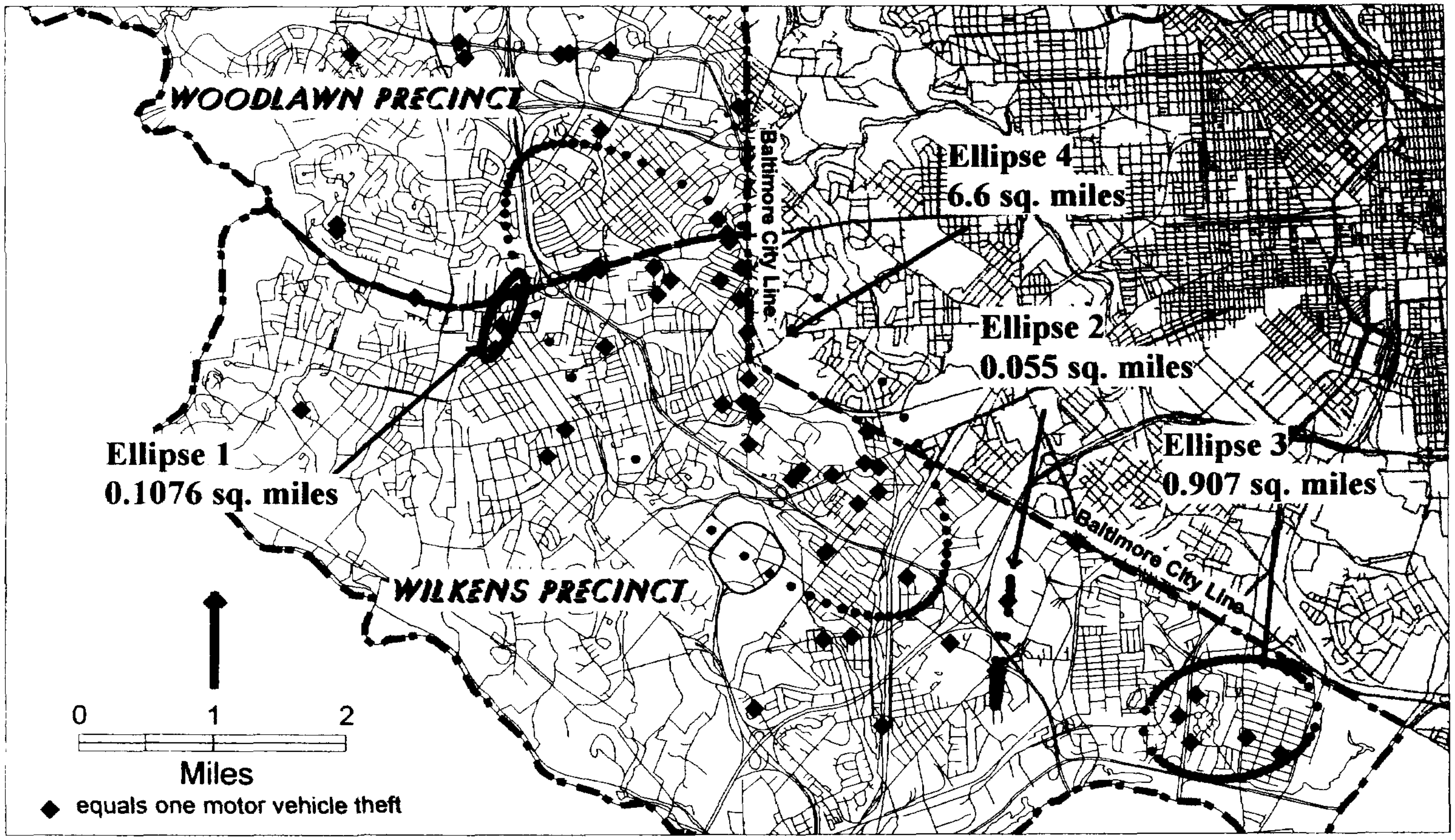
One method used by police analysts in Baltimore County to identify a high-crime area is a standard deviational ellipse. The standard deviational ellipse is computed using the Illinois Criminal Justice Authority's Spatial and Temporal Analysis of Crime (STAC). Input includes x,y coordinate pairs for each crime location, a search radius, and a set of parameters used to define the search area. Baltimore County crime analysts compute a search radius based on approximately twice the size of the area per point (Boots and Getis, 1988). Assuming that a map of the search area, or precinct, was overlaid with a square grid, the length of a grid's side would be determined by (2A/N) where A= the size of the search area and N= the number of crimes. The next step would be to circumscribe a circle around a square grid by finding the point at which the diagonals of the square intersect. The diagonals are equal to ([2A/N])/cos 45°), with the radius equal to one-half of a diagonal's length. As an example, suppose a total of 30 burglaries occurred in the Wilkens precinct over a two-week period. The Wilkens precinct has an area equal to 24.79 square miles. The length of a grid's side, (2A/N), would be equal to (49.58/30), or 1.29 miles. The search radius, 0.91 miles, is equal to one-half of a grid's diagonal, or (1.29/cos 45°)/2.

Figure 5 shows standard deviational ellipses for motor vehicle thefts occurring in the Wilkens police precinct during the last two weeks of September 1995. In an attempt to address boundary issues for cases occurring in a neighboring precinct, the search area defined by the STAC's SPACE parameter file overlapped approximately Va mile into the precinct contiguous to Wilkens. The search radius, 0.63 miles or 3,339 feet, was based on the 62 cases of motor vehicle theft occurring within the study area and the size of the precinct (24.79 square miles). Four ellipses or hot-spot areas were identified and mapped; three of the ellipses were relatively small in area, averaging 0.36 square miles, while the fourth ellipse contained 38 cases in an area of 6.6 square miles. With the possible exception of the second ellipse, a casual examination of the map suggests that the hot-spot areas produced by SPACE and delimited by the standard deviational ellipses do contain a high concentration of cases. There also appears to be some clustering of motor vehicle thefts among the cases contained within the fourth ellipse. The null hypothesis that complete spatial randomness exists for cases located within the fourth ellipse can be tested using a two-dimensional nearest neighbor analysis.

The longitude/latitude coordinates associated with each motor vehicle theft location are first converted to state plane coordinates. These coordinates are used in a spreadsheet as shown in Table 1, with each cell in the spreadsheet containing the distance from one theft location to all other theft locations. Note that the number of cases has been reduced from 38 to 33 because several locations represented by identical coordinates experienced multiple thefts over the two-week period. The coordinates associated with multiple theft locations were subsequently reduced to one coordinate pair since it is the relationship between locations, and not time, which is of interest. Also note that the diagonal shown in the distance matrix, which is the distance between one location and itself, was assigned a high value so that any other nearest neighbor distance wouldn't be excluded. The @MIN function in Lotus 1-2-3 was used to identify the nearest neighbor coordinate and distance, and the @AVG function was used to average the observed nearest neighbor distances. The observed average distance is compared against an expected value of the average nearest neighbor distance for a random sample of points approximated by the formula .(di)=0.5(A/N) and a standard deviation of $0.0683A/N^2$ (Boots and Getis, 1988). A z-statistic of -2.0, significant at the .025 level (two-tailed test), tends to confirm that the distribution of motor vehicle thefts within the fourth ellipse is not random. The negative z-statistic results from closer-than-expected average nearest neighbor distances, further suggesting that the distribution of motor vehicle cases is clustered.

The nearest neighbor analysis confirmed that the overall distribution of motor vehicle thefts within the fourth ellipse was not randomly distributed. Of particular interest to police, however, is identifying the location of cases that contributed to the apparent clustering effect.

Figure 5: Baltimore County, Maryland Motor Vehicle Thefts in Wilkens Police Precinct Last Two Weeks of September, 1995



Note: Shows four standard deviation ellipses for motor vehicle thefts. Standard deviational ellipses were developed by STAC available from the Illinois Criminal Justice Information Authority SPACE Analyzer program.

Table 1: Motor Vehicle Thefts in Wilkins State Plane Coordinates

		Distance To	ID	1	2	3	33
			YCOORD	517336.0	518309.0	520276.0	531823.0
Distance From			XCOORD	888245.0	885012.0	886280.0	880665.0
ID	YCOORD	XCOORD					
1	517336	888245		999999.0	3376.2	3536.2	16350.2
2	518309	885012		3376.2	999999.0	2340.3	14195.9
3 . . .	520276	886280		3536.2	2340.3	999999.0	12839.8
33		531823	880665	16350.2	14195.9	12839.8	999999.0

Note: Longitude/Latitude coordinates translated to Maryland State Plane Coordinates using BLMSPC27 coordinate conversion program. The Pythagorean theorem was used to compute distances from one coordinate pair to all other coordinate pairs.

These cluster "cells" are used by police analysts to identify areas targeted for directed patrol, surveillance, and crime prevention. The state plane coordinates used for the two-dimensional nearest neighbor analysis can also be used as input to a statistical clustering program. A cluster analysis procedure detects case groupings based on the closest case distances within a group and the largest distances between groups.

Five clusters, shown in Table 2, were selected using SYSTAT's K-means clustering procedure. Four of the five clusters within the fourth ellipse as well as the area delimited by the third ellipse, were targeted for directed patrol. Figure 6 shows the distribution of motor vehicle theft cases over a two-week period following the directed patrol strategy. The number of motor vehicle thefts dropped by 55%, from 62 cases to 28 cases during the first two weeks of October 1995. Most of the target areas identified during the last two-week period of September 1995 no longer existed during the first two weeks of October. Two notable exceptions, which were identified as hot-spot areas during the first two weeks of October, included additional motor vehicle thefts in an area originally located in ellipse 2, and a growing number of cases within the first cluster cell of the fourth ellipse. It is interesting to note that ellipse 2, while identified by STAC's SPACE program as a hot-spot area during the last two weeks of September, was not originally identified as a target area because it consisted of two cases. The number of cases located around ellipse 2 increased and spread geographically over the following two-week period. Most of the activity formerly located in the cluster cells associated with ellipse 4 ceased, the one exception being cases located in the first cluster cell which continued to occur and spread north of the precinct boundary possibly, as a result of displacement.

Space-Time Interactions

In some situations, police analysts in Baltimore County have noted that multiple offenses involving the same offender have a tendency to occur in the same communities over a relatively short period of time. For this reason a space-time interaction could suggest an association between a group of cases and an offender. In August 1995 a series of robberies began to occur in a 21-square-mile area of Baltimore County. The attributes associated with these cases were similar, but not identical, so it was initially difficult to determine whether the increase in robberies was due to a particular offender. For example, in some cases the robberies were committed by an individual and other times in pairs, there was no apparent type of location preferred, and the days of week varied. The only common case attributes, other than space and time, were race, gender, and type of weapon used by the offender to commit the crime. It was believed that any tendency for cases to cluster over time and space might support the possibility that these crimes were related to a common offender.

Analysts use the Knox method to detect simultaneous clusters in both time and space (Armitage, 1971). Based on known temporal and spatial characteristics of past robberies occurring within the 21-square-mile target area, analysts determined that on average a robbery occurs every one to two days and that the distance between sequentially occurring robberies averaged 10,732 feet, or about 2 miles. Eight robbery cases suspected of being caused by the same offender were paired and tabulated according to adjacency in time and space. The total number of paired cases is equal to N(N-l)/2, or 28 cases. Case pairs occurring within two days of one other were identified as being close in time, while those occurring under two miles were counted as close in space. A Poisson distribution was used to test whether the observed frequency differed significantly from a mean equal to the expected frequency. Table 3 shows counts associated with the observed and expected frequencies, as well as the probability associated with observing at least the number appearing in each cell.

Although the probabilities associated with each cell are not considered to be particularly significant, it is interesting to note that frequencies associated with cells close in time had the lowest chance probabilities. In fact, it was later determined that the eight robbery cases were committed by the same offenders.

Spatial Proximity and Diffusion Analysis

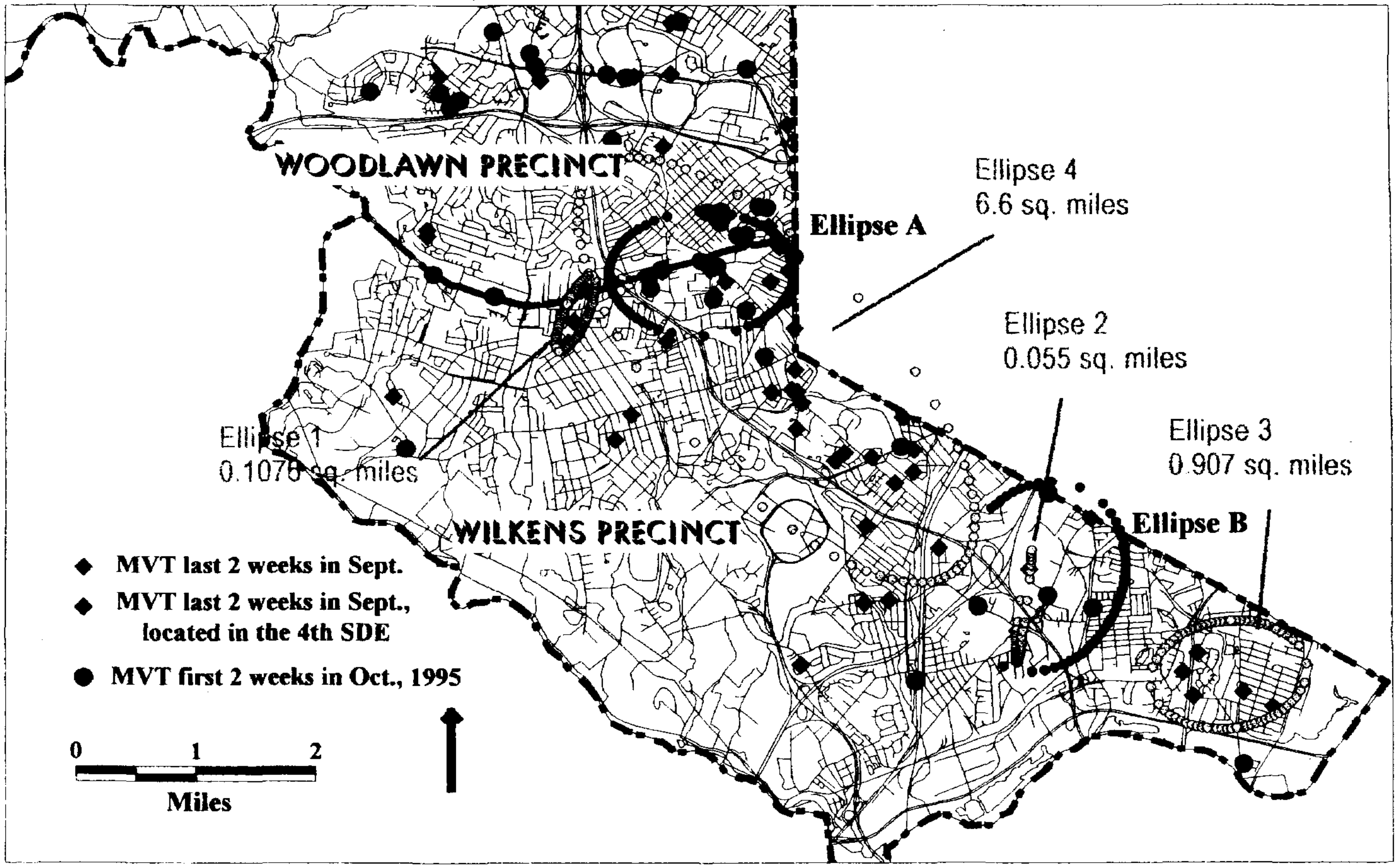
Police analysts in Baltimore County are frequently asked to examine relationships between crime and some geographic feature such as a school, transit station, or apartment complex. The ability to relate map features to some dependent variable is called spatial proximity analysis (Garson and Biggs, 1992). It presumes that a relationship exists between the map feature and the dependent variable. For example, Figure 7 shows robbery locations in proximity to a known drug market located in a low-income apartment complex in northwest Baltimore County. The map shows that robberies, as the dependent variable, tended to cluster within and around the drug market area. Police analysts have noted that an increase in street robberies located in and around high-density residential areas tends to correlate with

Table 2: Point Clusters (Motor Vehicle Thefts) Located Within the 4th Standard Deviational Ellipse Using SYSTAT's k-means Program

Summary Statistics for 5 Clusters						
Variable	**Between SS**	**DF**	**Within SS**	**DF**	**F-Ratio**	**Prob**
YCOORD	.494574E +09	4	.652590E +08	28	53.050	0.000
XCOORD	.435254E +09	4	.301599E +08	28	101.021	0.000

Members		Statistics				
Case	Distance	Variable	Minimum	Mean	Maximum	St.Dev.
Cluster Number :1						
19	1971.74	YCOORD	527255.00	529974.00	531823.00	1438.17
20	1037.29	XCOORD	880665.00	881199.50	881818.00	381.47
22	572.49					
26	267.16					
30	659.14					
31	660.37					
32	877.36					
33	1360.97					
Cluster Number: 2						
5	1861.04	YCOORD	521275.00	523516.25	525360.00	1373.23
7	1827.54	XCOORD	880796.00	882256.25	884039.00	993.87
10	613.07					
13	276.16					
14	1191.47					
15	648.41					
16	788.68					
17	1332.91					
Cluster Number: 3						
12	1299.14	YCOORD	523341.00	525004.00	526667.00	1663.00
18	1299.14	XCOORD	874552.00	875333.00	876114.00	781.00
Cluster Number: 4						
1	2636.38	YCOORD	517336.00	520641.75	523269.00	1840.07
2	1964.44	XCOORD	885012.00	886520.75	888245.00	974.56
3	309.62					
4	408.24					
6	1062.48					
8	908.46					
9	925.97					
11	1859.82					
Cluster Number: 5						
21	1135.65	YCOORD	528762.00	529568.29	529890.00	379.49
23	1345.26	XCOORD	875290.00	876836.00	878723.00	1324.25
24	1093.30					
25	666.47					
27	885.00					
28	779.75					
29	715.26					

Figure 6: Baltimore County, Maryland Motor Vehicle Thefts in Wilkens Police Precinct Case Displacement/Relocation



Note: Auto theft cases dropped 55% over a two week period following directed patrol strategy. Note change in the shape of ellipse 2 due to an increase in auto thefts (ellipse B). Also note change in cases near the precinct boundary (ellipse A).

Table 3: Counts Associated with Observed and Expected Frequencies, Along with Probabilities Associated with Observing At Least the Number Appearing In Each Cell

		TIME			
		Close	**Not Close**	**Total**	
S	**Close**	8	3	11	Observed
P		(8.25)	(2.75)		Expected
A		0.139	0.221		Probability
C					
E					
	Not Close	13	4	17	Observed
		(12.75)	(4.25)		Expected
		0.109	0.194		Probability
	Total	21	7	28	

drug activity. In Baltimore County, police analysts use a GIS to establish buffers or polygons around locations having a history of drug activity. Analysts can quickly monitor robberies occurring in and around drug market areas to determine whether a market is becoming active.

Using Geographic Information Systems to Develop Predictive Models: Baltimore County's Spousal Abuse Study (1989)

Between 1980 and 1989 the number of spouse assault cases in Baltimore County was increasing at an average rate of 6% per year, with a 78% increase in the number of spousal assaults per 100,000 people during the same period. In response to a growing number of domestic violence cases, Baltimore County Police started a Spouse Abuse Unit whose responsibilities included the collection of victim and suspect data that enabled police to identify and aggressively prosecute repeat offenders. Using the data collected by the Spouse Abuse Unit, police analysts in Baltimore County conducted a study with two objectives: (1) to identify locations and areas within the county that were experiencing a high number of spousal assault cases, and (2) to develop a model that could be used to identify areas where spouse assault cases were being underreported.

The first objective involved identifying spouse assault locations based on the incident address. Nine police reporting areas were subsequently identified as having a high number of spouse assault cases. A list of attributes including demographic, social, economic, and case information was associated to each area. It was noted that most of the incidents were located in areas with a high unemployment rate and a low median household income. This information was forwarded to precinct commanders for further attention as part of their strategic planning efforts.

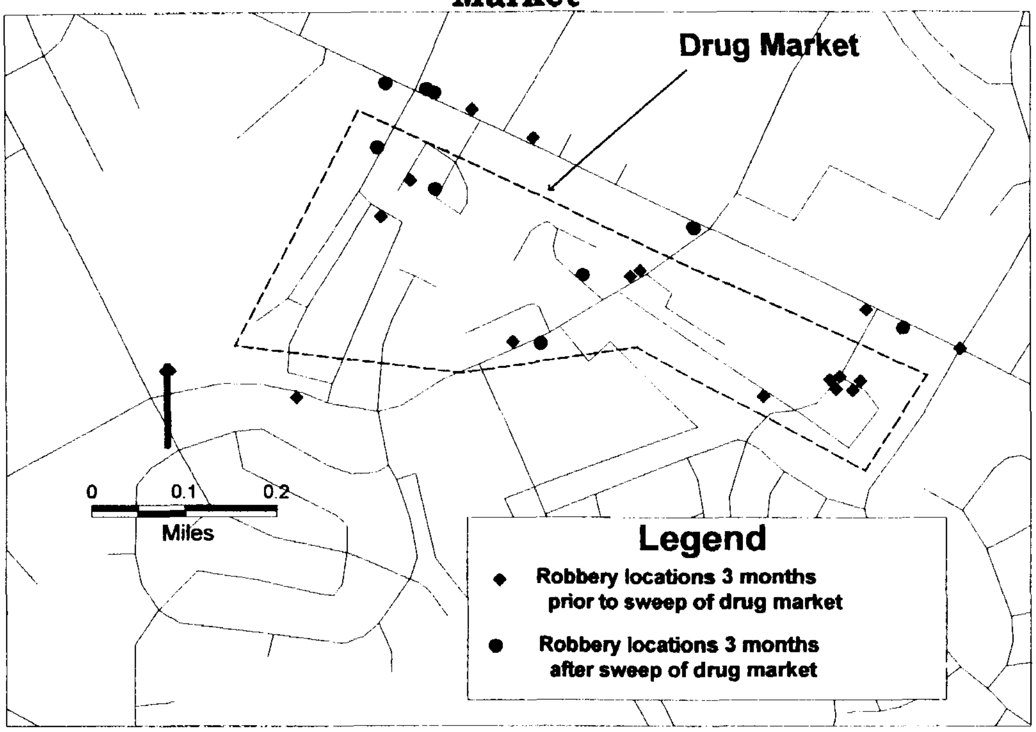
The second objective, developing a model to predict areas containing underreported cases, used 76 variables relating to income, employment, housing, population, drugs and alcohol abuse. Information was collected from a variety of sources, including the U.S. Census Bureau, the Baltimore County Department of Economic Development, the Baltimore County Office of Planning and Zoning, and the Baltimore County Office of Substance Abuse. Since most data was available by Census tract, police analysts used a GIS to aggregate point data such as arrests for driving while intoxicated (DWI) to Census tracts. A stepwise regression identified three variables that related to spouse assault: drug-alcohol charges (log), renter population (log), and unemployment rate (log). The three variables accounted for 64% of the variation in the dependent variable, or number of spouse assault victims.

The model produced a list of residuals or differences between the actual number of reported cases and the number expected given the values associated with each independent variable. The residuals were mapped and visually inspected for spatial autocorrelation. Although there was a tendency for residuals to group in areas that were predominantly African-American, a formal test for spatial autocorrelation using Dacey's test for contiguity revealed that the residuals were not spatially autocorrelated. In summary, the model was reliable in predicting Census tracts with a lower-than-expected number of reported spousal assault cases. Once these Census tracts were identified, precinct commanders used their community outreach officers to circulate information to residents about domestic violence.

Using Geographic Information Systems to Develop Crime Rate Denominators

Crime analysts in Baltimore County rely primarily on the number of incidents occurring within a particular area over a given time period to identify high-crime areas. In the process of studying the location of crime over a period of several years, analysts have noted that a small number of communities have a disproportionate number of crime. Upon closer examination, it appears that other factors like environmental risk or opportunity are influencing the number of crimes within these high-crime communities. For example, some po-

Figure 7: Robberies Located in Proximity to Drug Market



Note: Robbery locations in and around a known drug market area. Analysts have noted increases in robberies as drug activity in emerging markets increases. Note the decrease and apparent displacement of robberies after a sweep of drug market.

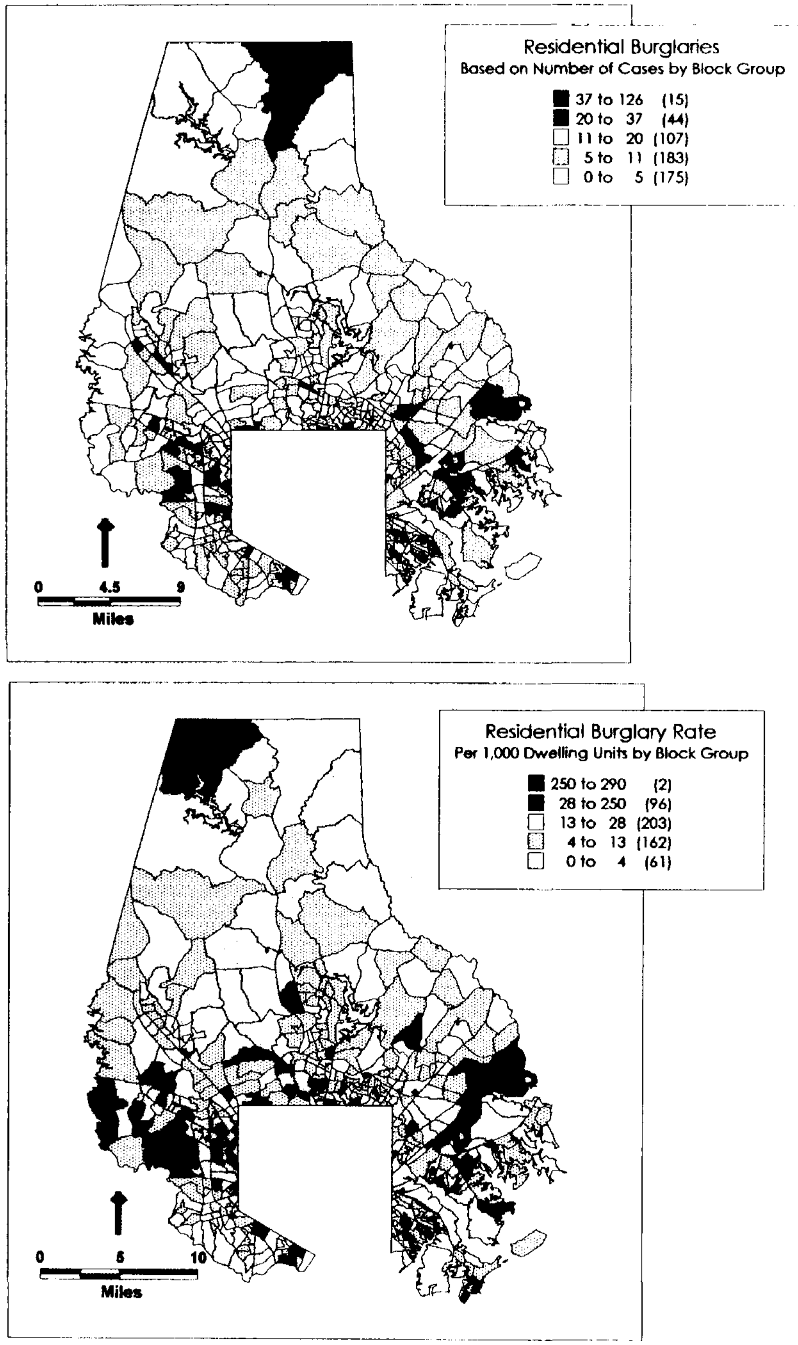
lice reporting areas in Baltimore County consistently have a high number of residential burglary cases, but these reporting areas also have a high number of residential dwellings. As expected, there is a strong statistical correlation (0.675, n=524) between the number of residential burglaries and the number of residential dwelling units within Census block groups, suggesting that the number of dwelling units is a direct indicator of residential burglary opportunity. Police analysts in Baltimore County use a crime rate denominator to provide an adjustment for opportunity.

Most of the data used to develop opportunity measures are contained in tabular files collected by other government agencies. Many agencies use a GIS to manipulate and map data contained in these files. For example, Baltimore County Police initially obtained information on the number of dwelling units by Census block from the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing System (TIGER). Census and crime data were subsequently aggregated to Census block groups using a GIS. Baltimore County's Office of Planning and Zoning is required under its Basic Services Legislation to monitor subdivision activity relative to critical services areas, so that the number of dwelling units is constantly updated to reflect changes in land use and growth. In this manner, police analysts have access to an opportunity measure such as the number of dwelling units that is updated and current.

Figure 8 shows two thematic maps of residential burglaries in Baltimore County by Census block group. A natural break method was used to define the five thematic class ranges for each map. The first thematic map shows the number of residential burglaries reported in 1995 by Census block group. A total of 15 Census block groups were classified as having a high number of residential burglaries. Nearly all of these Census blocks were rental developments, having a high percentage of rental units and a high number of dwelling units. For example, each Census block group in Baltimore County has, on average, 537 dwelling units. The 15 Census blocks classified as having a high number of residential burglaries averaged 1,353 dwelling units. Since we know that the number of residential burglaries tends to increase as the number of dwelling units increases, one can see why these 15 Census block groups would have a high number of cases.

The second thematic map was based on a residential burglary rate, or number of residential burglaries per 1,000 dwelling units. Using a natural break method to construct the thematic map revealed only two Census block groups as having a high number of residential burglaries relative to the number of dwelling units. Furthermore, the second map identifies some areas of the county as having a greater-than-expected number of residential burglaries given the number of dwelling units contained within the Census block group. This is apparent in some of the predominantly rural areas of Baltimore County.

Figure 8: Thematic Maps of Residential Burglaries



Note: The two thematic maps show the effect a risk measure, such as number of dwelling units, has on pattern and interpretation of a residential burglary problem.

Using a Geographic Information System for Community Policing in Baltimore County

One of the advantages of using a GIS is the ability to use and display large amounts of data. Information appearing on a map can be quickly synthesized and understood by a police officer, police commander, and, perhaps most important, the public. Most community meetings with Baltimore County police now include computer-generated maps of crime, with incident locations represented by colors and symbols corresponding to various types of criminal offenses. Maps can effectively communicate to the public that either a crime problem exists, or reassure a community that a problem may not exist. Overall, these maps are generally well-received by the public, primarily because there are usually significant differences between how the public perceives crime in their community compared to the reported crime displayed on the map.

It is apparent that in addition to other factors that may be contributing to problems in a community, data and information from a variety of government sources are needed by an officer as part of his or her problem-solving efforts. Crime remains an important measure of a community's health and well-being. Crime that is consistent and increases in frequency will negatively effect the viability of a community. Providing timely information about a community's crime problem is needed for a quick and effective response to the problem. Crime information at the community level must be available to police officers, and it must be in a format that can be quickly understood.

Over the last several months the Baltimore County Police Department has tied each of its eight precincts into the crime analysis database. Police officers now have the ability to access information on burglaries, motor vehicle thefts, robberies, drug activity, and field intelligence reports within 24 hours of the incident. Funded by the Maryland Governor's Office on Crime Control and Prevention, the department's Street Level Access Program (SLAP) contains the same databases and computer mapping features used by the crime analysts. Patrol officers can sit at a microcomputer and within one minute produce a map showing crime by precinct, post or community.

The SLAP system also has a report generator and a search utility that were designed by police and precinct commanders involved in community policing. Information about crime trends and patterns are electronically communicated to each precinct by the crime analysis unit, and, in return, field intelligence information on drug activity is communicated from patrol officers to the unit. This information will eventually allow analysts to identify surrogate indicators of drug activity in Baltimore County communities. Eventually, additional data collected by other government agencies will be available to patrol officers through the SLAP system, including the Drug Awareness Warning Network (DAWN), treatment data by Census tract, and other community viability measures.

CONCLUDING REMARKS

Law enforcement agencies have an established history of using innovative technologies to assist in suppressing and preventing crime. A majority of police agencies use computers and information systems for crime analysis and crime investigation. The location of crime and the use of geographic space by offenders are important components of the criminal event. There is, therefore, general agreement that information collected for the purpose of analyzing and identifying crime patterns and trends should include mapped crime locations.

GISs are designed to integrate and view descriptive information about phenomenon such as a crime in a spatial context. The ability of a GIS to map criminal incidents has enabled analysts in Baltimore County to effectively identify areas experiencing high-crime activity. Once high-crime areas are identified, computer mapping assists in the development and evaluation of interdiction strategies. Further, analysts can gain a better understanding of the relationships among crime, target, and offender patterns by relating incidents to geographic criteria. The ability to associate criminal incidents to other spatial information has allowed analysts in Baltimore County to explore a variety of factors influencing crime. Eventually, geographic models based on spatial attributes associated with factors influencing crime will be developed.

The multidisciplinary approach to the geographic study of crime has helped to identify concerns about assumptions used in spatial analysis. One could conclude that more study is required to gain a better understanding of crime within the dimensions of space/place and time. The use of GISs will undoubtedly be an important part of these studies. Theory not withstanding, there are practical applications in having police use GISs to assist in the prevention and suppression of crime. Foremost is the ability to use geographic information to efficiently and effectively allocate police resources.

♦

This chapter is dedicated to the memory of Kai Martensen whose tireless devotion and work in policy and management contributed to the advancement of the police profession nationwide. The Baltimore County Police Department is grateful to Kai for his vision and commitment to professionalism in law enforcement. We believe Kai would be pleased to see the technological advances in geographic information systems and crime analysis.

REFERENCES

Armitage, P. (1971). *Statistical Methods In Medical Research.* New York, NY: John Wiley and Sons.

Boots, B.N. and A. Getis (1988). "Point Pattern Analysis." In: G.I. Thrall (ed.), *Scientific Geography Series.* Newbury Park, CA: Sage.

Brantingham, P.J. and P.L. Brantingham (eds.) (1991). *Environmental Criminology.* Prospect Heights, IL: Waveland Press.

Bursik, R.J. (1988). "Social Disorganization and Theories of Crime and Delinquency: Problems and Prospects." *Criminology* 26:519-551.

Garson, D.G. and R.S. Biggs (1992). *Analytic Mapping and Geographic Databases.* Newbury Park, CA: Sage.

Harries, K.D. (1974). *The Geography of Crime and Justice.* New York, NY: McGraw-Hill.

Jeffery, C. R. (1971). *Crime Prevention Through Environmental Design.* Beverly Hills, CA: Sage.

Levine, J. and J.D. Landis (1989). "Geographic Information Systems for Local Planning." *Journal of the American Planning Association* 55:209-220.

Newman, O. (1972). *Defensible Space.* New York, NY: Macmillan.

Shaw, C. and H.D. McKay (1969). *Juvenile Delinquency and Urban Areas* (rev. ed.). Chicago, IL: University of Chicago Press.