SMART MAPPING FOR LAW ENFORCEMENT SETTINGS: INTEGRATING GIS AND GPS FOR DYNAMIC, NEAR-REAL TIME APPLICATIONS AND ANALYSES

by

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Abstract: *Crime analysis has long relied on maps for plotting crimes. Plotting crimes after they occur is a static process of historical data collection and reporting wherein data might not be plotted for many days, weeks, or months after the criminal event. SMART (Spatial Management, Analysis and Resource Tracking) mapping in law enforcement settings means integrating geographic information systems with dynamic location acquisition technology where near-real time data collection and analysis are possible. This article explores several possibilities for dynamic near-real time mapping applications for law enforcement. Examined are potential uses for small hand-held field equipment to plot "hot spots," boundaries, and other geographic characteristics, and for large automated vehicle location and artificial intelligence-guided emergency services dispatch*

INTRODUCTION

Historically, mapping out crime has been an important component of crime analysis. Today, whether by traditional pushpin or modern electronic plotting methods, crime mapping has become even more important as an analytical component of crime analysis. A review of

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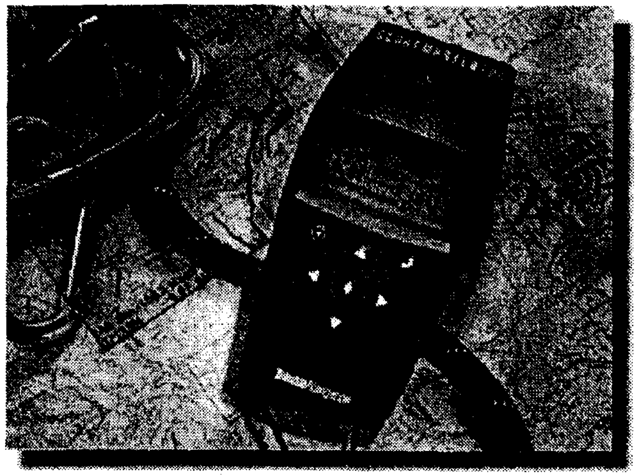

Figure 1: Picture Of Trimble Navigation's Scoutmaster GPS Receiver Capable Of Capturing Field Readings For Later Downloading On Computer For Precise Mapping Of Boundaries, Hot Spots, And Recordable Attributes

earlier chapters within this volume demonstrates many advances of crime analysis made through electronic mapping. However, with few exceptions, the uses of crime analysis and electronic mapping described in earlier chapters of this volume have been largely limited to examining static (non-real-time) data through temporal snapshots or maps of crime in time. Analysis of crime is routinely conducted days, weeks, or months after data are collected. This kind of electronic crime mapping can be a valuable intelligence tool to aid police in problem solving, but most of these analyses can be characterized as reactive and not proactive examples of crime analysis.

Mapping out crime in "real time" (i.e., as it occurs and is reported) can: reduce police response time; increase officer safety through real-time location identification; and increase the predictive capability of crime analysis, which in turn can lead to increased offender's risks of crime — a primary objective of situational crime prevention.[1] Mapping out crime in real time can enable law enforcement to conduct real-time monitoring, incident tracking, risk identification, and resource allocation. This chapter examines the integration of off-the-shelf technologies to conduct SMART (Spatial Management, Analysis and Resource Tracking) mapping for law enforcement. These tools have the potential to alter the mode of crime analysis currently conducted, enabling greater predictive functionality and operability. For example, dynamic or near-real time data collection and analysis can expedite the delivery of appropriate emergency responses through use of artificial intelligence algorithms that can rapidly identify crime incident location, closest emergency response personnel, and other characteristics to help the emergency response dispatcher to work smarter.

Real-time mapping operations require the integration of geographic information systems (GIS), global positioning systems (GPS), automated vehicle location (AVL) monitoring, and management information systems (MIS) integration. Together this alphabet soup of technologies constitute the SMART technologies.

This paper provides a primer on SMART mapping technologies and explores how they may be applied in law enforcement settings. SMART mapping technologies will be examined with respect to how spatial mapping, real-time analysis, and resource tracking can improve law enforcement data analysis and performance. Suggestions for crime data collection, spatial analysis, and the visualization of geographic data are provided. The chapter concludes with a discussion of potential advantages and drawbacks of using SMART technologies in law enforcement settings.

PRIMER ON SMART MAPPING TECHNOLOGIES

The backbone of the SMART mapping technologies are GIS, GPS, Management Information Systems (MIS), and AVL systems. On its own, none of these systems is sufficient for an effective SMART mapping system, yet together they create many opportunities for improving law enforcement.

Geographic Information Systems

GIS is a system of computer spatial analysis that links tabular (rows and columns) data to geographic boundaries and reference points. GIS computer programs may combine two types of data types: vector and raster. Vector data include typical row- and column-type data commonly used in spreadsheets. Raster data comprise other visual data that are mappable such as satellite images, photographs, and grid-system data, and that do not rely on vector-based row and column structures. Pioneered by the defense, energy, environment, and space research communities, GIS is one of the fastest growing technology areas worldwide.

The application of GIS to law enforcement is a relatively new phenomenon compared to the robust application of GIS within the engineering sciences.[2]

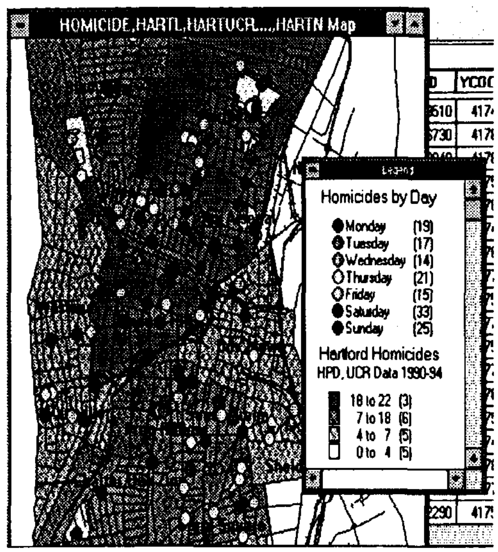

Figure 2: Example of a GIS Desktop Mapping System, Maplnfo Being Used to Analyze Homicides in Hartford for Years 1990 to 1994

Figure 2 depicts a typical crime analysis using a desktop GIS system. Using incident-based data from the Hartford CT Police Department, Sorensen (1995) found that clusterings of homicides were geographically linked to ethnicity in public housing settings. This Maplnfo for Windows chart uses shaded circles to show incidences of homicide by location, proximity, day of week, and neighborhood in Hartford from 1990 to 1994. The irregularly shaped polygons represent recognized neighborhoods and reporting areas. These neighborhoods are shaded according to density of homicides by area. Behind the map and legend appears a table in spreadsheet form that is the source of the crime data for the map.

Many law enforcement departments already conduct some form of crime analysis through mapping. The U.S. Department of Justice's Drug Market Analysis Program sponsored crime mapping projects in Hartford; Jersey City; Kansas City; Pittsburgh and San Diego, California. Subsequently, the U.S. Department of Justice sponsored two other pilot studies of mapping with the Montgomery County (MD) Police Department and the Warrenton (VA) Police Department. U.S. government-sponsored crime mapping projects represent limited coverage of what is happening in law enforcement departments nationwide. Many innovations are occurring worldwide as crime analysts are integrating mapping into their routine reporting and analysis.

The International Association of Crime Analysts reports that member analysts are mapping crime and related statistics in law enforcement departments throughout North America. A recent survey of members found that the most frequently used mapping program for crime analysis in law enforcement departments was Maplnfo, followed by Arc/Info, Arc/View, Atlas, and other packages (Sanford, 1996).[3]

Global Positioning Systems

GPS is a satellite array that provides a precise method of measuring latitude, longitude, altitude, direction, time, velocity, and other data at any location on Earth. While other methods are available to determine these measures, GPS performs these methods with great ease, accuracy and timeliness. A person only needs to push a few buttons on a mobile GPS receiver to record the information instantly. Depending upon the application, locational bearing information can be updated on a second-by-second basis.

A constellation of 24 semi-synchronous satellites (21 satellites and three active spares), located in orbit approximately 11,000 miles from Earth, makes GPS possible. Each satellite broadcasts specific atomic clock readings that are received and interpreted by GPS receivers. A GPS receiver must receive signals from three satellites to establish a two-dimensional fix (e.g., latitude and longitude or map grid coordinates, etc.), and four satellites to get a three-dimensional fix (e.g., latitude, longitude, and altitude). An unobstructed GPS receiver will see between six and to 8 GPS satellites at any one time.

The GPS system is funded and controlled by the U.S. Department of Defense. Initially, two accuracy levels for GPS receiver readings were created. Precise Position Service (PPS), is officially reported to pinpoint a receiver's location within ten meters and Standard Positioning Service (SPS), with an accuracy designed to be within 30 to 100 meters, was provided for state and local government and civilian usage. SPS-GPS readings, with error correction known as differential GPS (DGPS), are the signal readings most likely to be useful in law enforcement use settings. Although SPS-GPS signal readings are deliberately biased by the U.S. Defense Department to decrease pinpoint accuracy, commercial vendors have developed error-correction software that can increase accuracy to within 1 to 3 meters. This increased accuracy is achieved by using a fixed-point location with a known reference position, and introducing differential GPS algorithms to enable location positioning to filter out bias and other errors. The end result is that the DGPS is sufficiently accurate for law enforcement use, and much more cost-effective, than PPS-GPS.

GPS receivers range in price from several hundred dollars to many thousands of dollars. Hand-held units range from $100 to $4,000, depending on the accuracy level and features desired. Shown below are examples of two types of GPS receivers. The first is a hand-held unit that can be taken to the field to collect precise location readings that can subsequently be downloaded into a computer and mapped.

Figure 3: Hand-Held GPS Receiver

The second image is of a personal computer (PC) card-based GPS receiver that allows real-time data collection and monitoring. This system is used in vehicles with dynamic GIS maps that provide a second-by-second map with refreshed positioning. When this system is combined with a portable radio transmitter, such as a cellular phone or a two-way radio, it can receive GPS signals from a receiver at a distance from the data interpretation point (limited only by the signal strength of the transmitter and radio receivers).

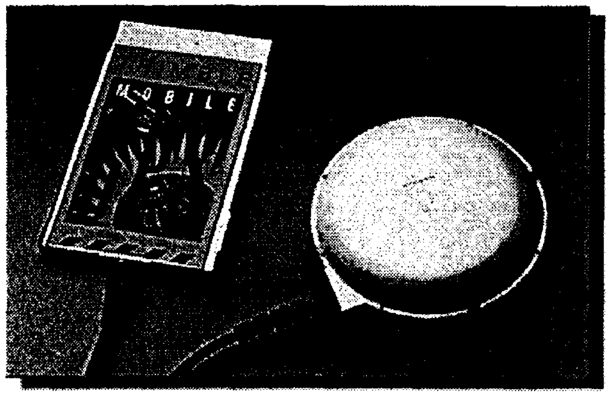

Figure 4: PC Card-Based GPS Receiver

Alternately, the GPS receivers can be mounted on the automobile dashboard, window, or exterior of the vehicle. Miniature GPS receivers can be hand carried, uniform holstered, or wrist mounted. The application purpose determines the equipment, size, accuracy, and features required.

Management Information Systems

MIS computer databases are used extensively by GIS and GPS applications. MIS databases include accessible data with reference points that are mappable. Such spatial data include boundaries such as Census blocks, block groups and tracts, street addresses, zip codes, police zones and districts, patrol areas, political boundaries and jurisdictions. These systems are essential to providing storage for access and application of GIS and GPS data. Examples of law enforcement GIS applications include emergency response systems, drug market analysis programs, offender tracking programs, gang identification programs, and historical databases.

The following image illustrates an example of using *On Target Mapping's* "Drive" time analysis software, a MapInfo add-on module, to determine the best paths by time and distance measurements. Notice that the dispersion of shaded paths is uneven, and that rivers and unnavigatable areas are not eligible for consideration. Through this module, the operator can control up to 36 variables to create realistic representations of time-distance relationships. This type of drive time analysis is an excellent illustration of the integration of MIS and GIS systems. When combined with a GPS receiver, the map could be used to track distances by car, foot, train, or other distance-time measures.

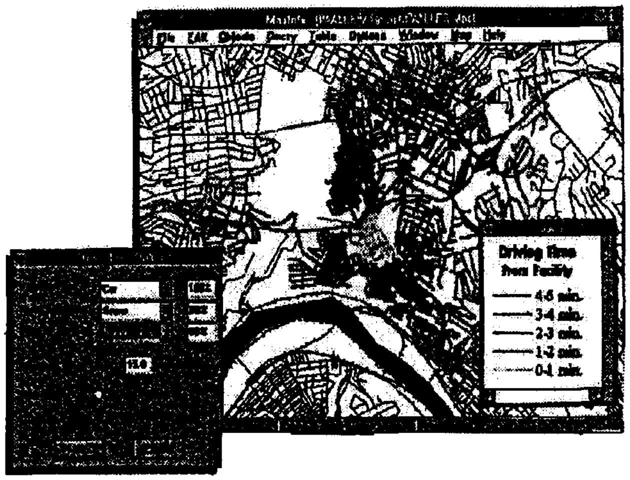

Figure 5: Example Of A Screen From On Target Mapping's "Drive" Time Analysis Software

Use of integrated tools allows analysts to make distance calculations in terms of the following distances:

- Euclidean (i.e., "as the crow flies")
- Manhattan (i.e., "as the taxi drives")
- Drive time under non-optimal conditions, walk time, etc.
- Network
- Ground
- Spherical, and
- Map projection

Use of the appropriate distance measure increases data reliability for analysts and law enforcement officers. For example, using Manhattan distance following only allowable street patterns can help determine the optimal emergency response personnel based on drive-time distance.

CURRENT AND FUTURE RESEARCH APPLICATIONS FOR INCIDENT-BASED CRIME DATA

In 1991, the U.S. Department of Justice's *Incident-Based Reporting Project Advisory Board* conducted a survey of current and potential uses for incident-based data.[4] Applications included identifying largely static mapping outcome such as:

(1) Victim-offender relationships
(2) Costs of crime
(3) Drug/alcohol involvement in crime
(4) Crime rates by population characteristics
(5) Spatial analysis of offenses
(6) Residency of victim and offender
(7) Use/involvement of weapons
(8) Hate/bias-related crimes
(9) Secondary crimes in events
(10) Crime rates by offense type
(11) Tracking arrested offenders
(12) Development of new indices
(13) Characteristics of cleared offenses

All of these are reported as static measures of measurable data, and are most often collected and analyzed some time after the events occur. Some of the measures, such as tracking arrested offenders (or probationers), lend themselves to dynamic tracking. The accuracy and real-time use of the above crime measures and indices (excluding 2 and 13) may be improved or made more valuable or predictive through dynamic, real-time, SMART mapping.

Situational Crime Prevention and Applied Technology

The emergence of new mobile technologies such as cellular phones and portable radios has challenged the supposition that rapid response is not efficacious. Near-real-time and mobile responses made possible with new technologies have enabled emergency response personnel to respond more quickly and with increased intelligence to time-sensitive events. In the past, the time lag between the time when crimes occurred and when law enforcement responded was significantly long so as to discredit the notion of rapid response as a crime deterrent. Rapid response was discredited as a crime prevention tool as the distance decay from criminal event to reporting made even efficient events time-lagged responses. Community policing reemerged as the crime prevention approach of choice. However, recent advances in technology will enable real-time and near real-time response.

Linking GPS tracking capability with GIS mapping programming can significantly lessen the distance decay from point of infraction to intervention. Several possibilities for crime prevention are availed through these technologies. Computer-aided dispatch can be made smarter through the ability of GPS to inform GIS emergency response systems with accuracy and timeliness. Linkages to MIS can provide best-route information, reference traffic congestion, and predict close approximations of response times to assure callers. GPS receivers linked to mobile computers can be used to map out the locations of crime, drug markets and gang activity, or to map out the boundaries of roads, fence lines, reporting areas, etc., or other characteristics impacting crime reporting. Standard-mounted GPS receivers located on emergency response vehicles can provide real-time position monitoring, and can potentially reduce emergency response times by providing vehicle location, drive time analysis, and database referencing to provide the most appropriate and timely response for each situation. Miniature and disguised GPS receivers with radio or cellular transmitters can be used to provide discreet real-time position monitoring of personnel, vehicles, shipments, and other targets to increase operational safety in sensitive law enforcement operations by allowing for non-human technical surveillance at a distance. Wrist-worn GPS units could become part of standard uniform for patrol and operations officers, allowing for real-time technical support and officer-down alerts and tracking. The additional option of remotely turning off the GPS units could make them inoperable if compromised or stolen. Crime analysts can gain data integrity improvement through the use of GPS- and GIS-linked real-time position monitoring. GPS asset tracking (personnel and vehicles) can increase analytical power of law enforcement by providing better data useful in modeling crime events by time, location, and proximity to other geographic characteristics.

In the future, dynamic real-time crime maps will be available for law enforcement officers on patrol. GPS-assisted law enforcement asset position monitoring and radio feedback can allow for active data exchange of historical data to create dynamic crime contour maps (e.g., three-dimensional topographical maps) that can be useful to officers on patrol. Moving maps displayed on mobile computer notebook screens could provide predictive and historical crime pattern information of offenders and victims, as well as use of space information. Other potential uses of dynamic mapping in criminal justice settings are described in the following section.

SMART MAPPING LAW ENFORCEMENT APPLICATIONS

This section describes how specific objectives can be achieved through SMART mapping to reduce response times, and to increase appropriate response likelihood, officer safety, and offender risks associated with crime.

Real-Time Response and Opportunity Reduction

When GPS and GIS are linked with emergency response systems, they can systematically reduce dispatch time and error, which in turn can lead to more rapid response and crime opportunity reduction. One such system, AVL, is an enhancement to computer-aided dispatch. A combination of AVL and GPS provides a public safety agency with the ability to identify the location of every emergency response vehicle, and to dispatch the closest, most appropriate units to the scene. AVL requires the capability to determine emergency vehicle location, communicate with the response vehicle, and track the vehicle's location into an interpretable format for the dispatcher. With GPS, AVL can operate within seconds. AVL can use several methods of locational proximation, of which GPS is the most dynamic and accurate. The best AVL systems use GPS to increase their accuracy and timeliness of response. Many older AVL systems require the dispatcher to manually consult a map and locate the nearest assets to respond to an emergency. When GPS is linked with AVL, human interaction is guided and time between need and dispatch is minimized. Consider the following situation.

A call for assistance is received. While the operator speaks with the caller, the emergency response computer quickly identifies the location of the call through GIS tracking enabled by enhanced 911. The computer swiftly "pings" its visual "radar screen" to determine which emergency vehicles are available to respond swiftly. The system then selects the most appropriate vehicle and alerts it. The GPS system is able to update the computer system each second with new information on the location, availability, and status of each law enforcement officer and asset within the system, and thus can consistently provide the most accurate information. While the system is locating a vehicle, an automated search request is forwarded to the MIS system database that aids the process by identifying technical resources, equipment, and the training level of officers within each vehicle. Accordingly, a set of predetermined algorithms guides the law enforcement response selection process, as the SMART mapping system identifies and ranks law enforcement personnel by proximity to the location. At the same time, a GIS drive time analysis is identifying natural barriers of rivers, obstructions, street types, traffic congestion, and road closures, and estimating drive time. The GPS system updates the process on a second-by-second basis. An estimated time of arrival is communicated to the caller, and real-time monitoring is available to the dispatcher.

The components of this scenario could be conducted in a matter of seconds, almost seamlessly, enabling the computers to increase operational response through appropriate law enforcement asset selection and resource allocation. Such situations are not merely hypothetical. Several early integrators of AVL applications in law enforcement include: the Michigan State Police, the California Highway Patrol, the Montgomery County (MD) Police Department, and the Schaumburg (IL) Police Department.

Real-Time Tracking and Risk Reduction

A second use of this technology for law enforcement is to improve operational safety. Consider the following situations.

In the first example, narcotics detectives wish to follow a known suspect. A discreet GPS device has been mounted on the suspect's vehicle. GPS signals are transmitted from the suspect's vehicle, via miniature radio receiver, and are captured by the tracking vehicle. The signals provide latitude and longitude coordinates or map grid coordinates, as well as altitude (height) bearings (e.g., geographic topography, building floor elevation, etc.). Officers tail at a safe distance, observing the signal of the target vehicle as it appears on their portable notebook computer screen is equipped with GIS-GPS tracking software.

The second example concerns organized crime detectives who are working on foot and who become separated. Miniature wristband GPS devices signal, on a near-real-time basis, each agent's whereabouts to other field agents who are supervising the undercover operation. A man-down switch on one of the detectives' GPS receivers is toggled. The supervisor observes that the signal from the officer's GPS unit is rapidly leaving the target area. Monitoring software enables the supervisor to swiftly identify the direction and bearings of the signal. The GPS tracking beacon enables support officers to locate and rescue the detective, who had been taken hostage and was being held in a previously unknown warehouse operated by a criminal organization.

Clearly, in both these situations officer safety and operation integrity are improved through the use of SMART mapping technologies.

Forecasting and Crime Opportunity Avoidance

Use of SMART mapping need not be limited to responding to current events. Consider the following proactive situation. A metropolitan city has invested in a SMART mapping systems that integrates GPS, GIS, MIS, and AVL systems technologies. Patrol officers' automobiles are equipped with notebook computers linked to GPS devices. As each vehicle moves throughout the city, a dynamic three-dimensional map showing latitude, longitude, and crime incident probability (or history) would provide a real-time cityscape of crime probability in visual topographical form. Peaks and valleys, representing crime hot spots and cold spots, are visible. Data is updated from departmental computers via radio signals that are fed into the notebook computers. Day of week, time of day, weather patterns, and historical data guide the visualization of data projected on the screen. The forecasting model visually represented may also include actuarial data informed by known probabilities of crime in and around different types of buildings. Officers observe their assigned communities with new eyes. As an infrared camera brings new vision to the night blind, a GPS-GIS law enforcement visualization model can bring new vision to officers' perception of the crime around them. This new vision could greatly assist officers in being proactive in crime situations. Officers trained to use this information to seek out the high-crime areas in their communities could proactively reduce crime opportunity by patrolling and suppressing locations that were identified as having a high likelihood of crime incidents.

Other Research-Based Applications for Mapping and Crime Analysis

Cutting-edge work in crime mapping is being conducted by several influential criminologists, geostatisticians, and practitioners. Recent innovations include:

- Rossmo's (1995a, 1995b, 1994) Isocrime Mapping and Criminal Geographic Targeting.
- C.R. Block and R. Block's (1994) STAC Hot Spot Ellipse Identification tool.
- P.L. Brantingham and P.J. Brantingharn's (1994) offender location and place pattern analysis, which incorporates actuarial data such as building site, zoning, use profiling, and risk assessments.

- LeBeau's (1994) incorporation of three-dimensional crime interpolations into spectral analysis.
- Canter's (1994) integration of health and police data into drug market analysis.
- Weisburd (1995, 1992) and Green's (1994) identification and definition of drug markets in geographic settings.
- Additional mapping contributions on various topics by Rengert (1994), by Maltz (1995, 1994), and by Eck (1995, 1994).

These research applications and many others have been incorporated into practical-use crime mapping in U.S. law enforcement settings.

Similarly, crime offender and victimization profiling can be integrated into mapping for specific purposes. For example, the San Bernadino Sheriffs Office uses mapping to recognize and detect serial burglary patterns using factors of:

- Time
- Date
- Weapons involved
- Victim statistics
- Offender statistics
- City map data

Environmental factors influencing theft of cars (Poyner and Webb, 1991) also could be integrated into algorithms suitable for identification of markets and potential victim locations. Auto theft's mappable traits include:

- Crime rates
- Owner-occupied housing
- Presence of driveways
- Presence of garage
- On- and off-street parking
- Communal parking
- Facing direction of house
- Through pathways on the property

Drug investigations can be enhanced through the integration of mapping of factors that include:

- Computer searches
- Offender investigations
- Vehicular investigations
- Historical conspiracy investigations
- Laboratory forensics investigations

- Habitual offender tracking
- Financial document tracking
- Offender asset tracking

Police performance and understanding of crimes can be improved through mapping of such physical evidence as:

- Laboratory analysis of drug samples
- Fingerprint analysis
- Field testing of drug samples
- Weapons seizures
- Bullet analysis

Electronic surveillance data can be integrated with mapping to produce near-real-time and real-time applications that would improve officer safety, enhance law enforcement performance, and reduce response time. Such applications and technologies include:

- Mobile communications-assisted vehicle, personnel, and target tracking
- Hand-held GPS data collection and monitoring tools
- Wireless microphones used at peripheral locations creating audio tripwires that report back location of incoming or outgoing targets
- Counter-surveillance equipment

Undercover operations, collateral intelligence-gathering activities, and performance records can be mapped with information on the location, offenders (buyers and sellers), setting, and time. Among these covert efforts are:

- Buy/Bust
- Buy/Walk
- Reverse-Sting
- Sting
- Precursor chemical enforcement

Precursor chemical enforcement can be dramatically enhanced through the integration of the following data sources.

- Precursor chemical control
- Audits of suppliers
- Audits of manufacturers
- Audits of pharmacies
- Audits of medical doctors
- Seizure data

Although the legal and moral implications of using this electronic equipment must be considered carefully before implementation, the following additional electronic technical measures can be highly valuable when integrated into mapping:

- Still camera systems
- Video/closed-circuit television systems
- Mobile video systems
- Night vision equipment
- Thermal sensing equipment
- Aerial photography
- Remote sensing
- Offender photos
- Suspect trails

A comprehensive listing of mapping possibilities for crime analysis appears in the Appendix.

SMART MAPPING ANALYTICAL AND VISUALIZATION POSSIBILITIES

The value of mapping in relaying complex information cannot be overstated. Simply expressed, if it is true that a picture is worth a thousand words, then it is also true that a map is worth a thousand numbers (paraphrased from Berry [1993]). Visualizing data communications helps transfer information through the lowest common denominators of expression. The French proverb, "that which is understood, can be expressed simply" applies to mapping. Visualization of data is useful in presenting concrete facts, directions, processes, bits of data, comparative data, data recorded over time, organizational structures, places, chronologies, generalizations, and theories (Wileman, 1993).

Why Analytical Visualization?

Mapping is statistics made simple. The eye can easily understand visual depictions of the results of complex mathematical computations. Peaks and valleys in maps inform the viewer of high spots and low spots without requiring that he or she understand how such information was mathematically created. Consider the following illustration of a two-dimensional Interpolation.

Data that lie on a two-dimensional grid can be interpolated by using splines that run in two directions. These data may be characterized by the following function.[5]

Consider the relation:

$$i := 0..10 \qquad j := 0..10 \qquad A_{i,j} := \sin(i)\cdot\cos(j)$$

where the following equations create a smooth csplined surface map.

$$m := 0..40$$

$$n := 0..40$$

$$Y_m := \frac{1}{4}\cdot m$$

$$D^{<j>} := \text{cspline}\left(R, A^{<j>}\right)$$

$$K_{j,m} := \text{interp}\left(D^{<j>}, R, A^{<j>}, Y_m\right)$$

$$V^{<m>} := \text{cspline}\left(R, K^{<m>}\right)$$

$$S_{n,m} := \text{interp}\left(V^{<n>}, R, K^{<n>}, Y_m\right)$$

The result of these calculations can be shown in a contour map. Completing such calculations will yield numerical data that are not easily interpretable. These numerical data pale in comparison to the observational intuitiveness of visual mapping and cognitive identification. The results of the calculations are depicted in the contour map below. Hot spots and cold spots are readily observed as peaks and valleys. Color differentiation shows gradations of effects along a continuous surface map.

Other spatial data reference coordinates such as streets, places, boundaries, operations, zoning, occupancy, and rates of crime can be represented in a similar map. The opportunities for crime analysis and law enforcement operations are enormous. Maps such as these would enable law enforcement officers on the street to visually associate these peaks and valleys with surface coordinates at the neighborhood level. Such visualization would greatly enhance the translation of crime data analysis to on-the-street policing.

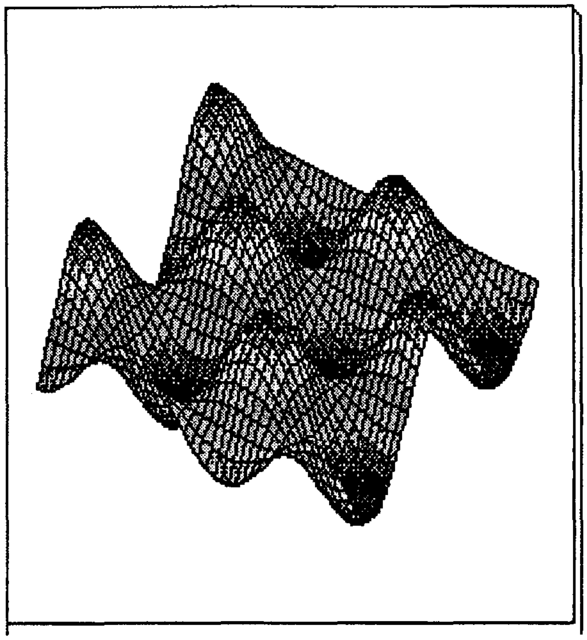

Figure 6: This Contour Map Displays The Results Of The Above Equations

SMART Rooms or "Situation Rooms" with Large Screen Monitoring

Visualization of data may be eventually be extended to SMART rooms or "situation rooms." Real-time monitoring of emergency response system assets can improve situation management. Such situation rooms could serve as dispatch and emergency response headquarters, or, in a portable form, be used for tactical law enforcement operations and planning.

Mobile Crime Topography and Dynamic Contouring

Eventually, advances in communications and crime modeling will enable officers to view historical crime pattern data on mobile computer screens, perhaps projected on the front windshields of their patrol cars. As officers passed through neighborhoods, the GPS receiver would update their position coordinates and their maps would be refreshed, with crime data appearing as peaks and valleys in a topographical layout.

The display could include streets, crime modalities, and crime hot spots. As a dynamic map, it could serve as a predictive play book for crime prevention. Officers could direct their efforts to suppress criminal activity to the peak areas, as indicated by the map. Fast rates of data exchange and monitor refreshing, combined with mobile data terminals, could enable officers to confirm identification of vehicles and persons contacted.

SMART MAPPING CAVEATS AND VULNERABILITIES

While SMART mapping has many obvious potential benefits, there are also some caveats which should be considered before pursuing widespread acceptance of the technology within law enforcement settings.

Does Real-Time (or Near-Real-Time) Response Prevent Crime?

One must address the issue of real-time or near-real time response. One of SMART mapping's greatest strengths is its ability to relay data in near real-time and thus increase officer response speed. It is important to determine whether this access to near real-time data in this form will help law enforcement officers to be more effective in fighting crime. The question that must be answered is, "Does real-time (or near-real time) response prevent crime?" In the 1990s, the cycle of law enforcement practices has come full circle so that community-oriented policing is again in vogue. Once-popular rapid response methods have gradually been overtaken by community policing methods.

While SMART mapping can clearly support community-oriented policing, most mapping applications to date have been problem-oriented. A potential outcome of law enforcement use of crime mapping is that enforcement agencies with short-term performance goals may stray away from community policing models in favor of specific situational intervention models, in the hope that SMART responses (being both rapid and appropriately efficient) might bring early success. It is important that community policing not be abandoned. Law enforcement agencies that plan to introduce SMART mapping need to be aware of its impact on alternate models and programs.

Privacy Concerns

For some purposes, SMART technologies may be too smart. To individuals concerned with conspiracy, the specter of "big brother" watching is reinforced by the onset of smart technologies that include integrated GIS, GPS, MIS, and AVL technologies.

Anecdotal reports collected while preparing this article included repeated concerns from police union members that law enforcement officers risk losing their privacy through real-time surveillance of officers. The fear that the power of GPS tracking technology might be turned inward and used for internal police manpower analysis purposes is not unreasonable.

Reports of intra-department GIS system sabotage by police officers and damage to GPS tracking systems on patrol units is not uncommon. The purpose of GPS systems in law enforcement settings needs to be clearly defined. Limited goals of smart response (being both rapid and appropriate), officer safety, and operational integrity may be required to encourage acceptance of the technology within law enforcement settings.

Potential Misuse of SMART Technologies

Beyond privacy concerns, there are other — more sinister — possibilities for SMART technologies. Rarely have tools made for positive purposes not been turned to negative purposes by someone seeking gain or reward. Criminals and terrorists could potentially access such technologies for tracking or targeting individuals. An organized crime operation would have a considerable advantage if it knew the exact location of all law enforcement assets at any given time. Governments (or individuals with government access) could also abuse this power. The courts have kept a tight hold on the use of eavesdropping technologies. The use of GPS technologies for tracking has many uncharted and unlitigated boundaries that must be established. It is likely that abuses of this tracking technology will provide the impetus for instituting these regulations. However, the potential for misuse is inherent in the technology.

Technical Limitations

Beyond concerns of harmful human misappropriation, there are technical limitations that will be encountered in implementing an aggressive technology policy. The best crime modeling approximations are still not entirely free from error. In law enforcement settings predictive capability is valuable, yet cannot replace the need for conventional law enforcement coverage. For example, a crime predictive model could predict with some certainty that crimes were likely to occur during certain periods or days at particular locations. However, while increased patrols could be assigned to the identified areas, one could not reasonably abandon enforcement of other areas without increasing crime opportunity risks in those areas.

GIS data are limited by the accuracy of several inputs that directly influence outcomes. Incomplete incident reports, wrong addresses, improperly entered dispatch reports, geocoding errors, street-file imperfections, and human error all complicate the analysis of data and can introduce bias that limits its usefulness. GPS receiver signals are imperfect. GPS error sources are a combination of noise, intended bias, and blunders. Noise and clock bias occur within the GPS receiver itself, which distorts readings. GPS receivers use crystal oscillators that are much more inaccurate than atomic clocks used in GPS satellites.

Beyond mechanical bias, some errors are deliberately instituted by the U.S. government when it seeks to degrade the signal quality through a time-varying bias. Recent GPS and GIS field testing (Sorensen et al., 1996) conducted in August 1996 in and around the San Francisco Bay area found that deliberate GPS signal bias was greater during nighttime hours, rendering simple GPS receivers worthless without Precise Positioning Capability to adjust for error. Further, each satellite's bias is different, which complicates correcting the bias and thus adds to the overall inaccuracy. The combined biases of all the satellites reduce the basic accuracy of signal readings for around 30 to 100 meters, or, in the case of San Francisco, several blocks during nighttime use. Consequently, bias-correcting differential algorithms are necessary to increase accuracy for law enforcement purposes. Other bias errors occur through satellite clock errors; topospheric delays (due to changes in humidity, pressure, and temperature); ephemeris data errors; and unmodeled ionosphere delays, etc. (Dana, 1997).

Beyond bias and system errors, GPS is also vulnerable to human interventions such as jamming of signals and spoofing or false signals. Dithering of signal accuracy at variable levels beyond the designated 100-meter error level can be expected during increased national security uncertainty. Presently, such dithering or distorting signals are largely limited to national security situations, but it is not entirely unwarranted to consider the possibility of interventions by organized crime groups if they were aware of law enforcement's use of the system.

Another problem encountered in using GPS systems is that GIS maps are conceived on a national level and so do not always reflect local settings. For example, addresses in many public housing settings are listed in terms of individual building names. A GIS map, however, might group the entire development by its street address, and not make the distinction between particular buildings or apartments. GPS can overcome this by precisely locating positions within formerly non-mappable locations. For example, a hand-held or portable GPS receiver could be carried or driven on new streets, fence lines, building exteriors, etc. to create a digital file of points representing the previously non-mapped characteristic. This data can be amended to one's existing GIS data files to incorporate the new geographic characteristics found in the field. However, in this instance, prior to use a human-resource cost of labor, time, and equipment must be used to characterize the new street or geographic feature. Beyond static map files, dynamic mapping places additional memory resource requirements on GIS computer systems to respond to multiple requests in dynamic environments. The capital costs can be enormous.

Certainly, it would not be cost-efficient to fund implementation of a GPS system if reliable backup technologies were not already included in the emergency response plan. Too great a reliance on GPS systems could prove to be disastrous if something were to interfere with law enforcement's ability to use the system. For instance, the same GPS system that guides police vehicles can guide missiles. It is unrealistic to think that the standard-positioning GPS guidance systems would remain operational during wartime. Other tracking systems such as dead-point reckoning, LORAN (long-range radio positioning system), cellular phone, or other radio-based tracking system can be used as backups and should be factored into the design phase.

Incompleteness

To accurately map crime, one must ascertain that crimes have been committed, and that the crimes have been recorded accurately down the data chain. James Q. Wilson's (1975) caution concerning data validity is doubly true with respect to crime mapping. For data to reflect real-world conditions, crime must be perceived, defined, and reported. Mapping requires additional measures to ensure accuracy, including: testing and routinely upgrading street files for integrity and accuracy; filtering data for imperfections; and ensuring that data is accurately recorded, processed and analyzed by all persons who handle them, from the officer responding who files the report, to the booking clerk at the jailhouse, to the data entry clerk preparing data for computer analysis, to the crime analyst examining the data.

Cost and Training

Financial barriers to implementing mapping systems have decreased dramatically over the past five years, but are still not insignificant. Mainframe systems can be replaced by smaller yet still powerful RISC workstations, and desktop mapping systems have increased in power and sophistication. Desktop GIS systems with the highest numbers of licensed users include high-end GIS packages such as ESRI's Arclnfo (ESRI) and desktop packages such as Maplnfo Professional, V.4, ESRI's ArcView 2.0, and Strategic Mappings (Atlas GIS). Numerous other packages are available and documented on the Internet and can be found using search tools querying "GIS," mapping, etc.

Digital files required for mapping streets in the U.S. once cost many thousands of dollars, but can now be purchased on a series of CD-ROMs for less than $400. Recent U.S. Geological Survey Map files (Tiger 94) have improved in accuracy since the Tiger 92 version. Still, in order to fully work within a seamless GIS system, these files need messaging as new streets may be created, numbering systems may change, etc.

Basic hand-held GPS receiver units now cost between $100 and $350, while more sophisticated hand-held units now cost upward of $500 dollars each. This price does not include additional accessories that are necessary for an interface "box," such as the GPS system, modems, radios, sensors, monitors, and other peripheral devices. It also does not include the price for radio frequency transmitting devices with repeaters or digipeaters; an interface "box" (device to pass data from the radio to the computer), charges for local GPS error correction, or a local running AVL-inclusive SMART mapping package. These things together will result in a GPS system capable of managing law enforcement assets using real-time information. Fortunately, today's trend toward off-the-shelf (as opposed to design-built) technologies will probably continue to lower prices while keeping compatibility (and interchangeability) high. This can only benefit law enforcement.

The time needed to learn SMART mapping applications can be great. Training costs are high in terms of dollar costs per hour. However, as more GIS-GPS applications become available in the form of off-the-shelf commodity packaging, their user-friendliness should increase, thus minimizing training times and costs. Currently, the learning curve for all software packages mentioned above is steep. Desktop packages require several days of training, and the more complex workstation packages can require six months or more.

CONCLUSION

Crime mapping plays an increasingly important role in crime analysis. Spatial analysis tools and techniques, accompanied by the improved data accuracy afforded by GPS systems, can improve law enforcement response time, officer safety, asset allocation, and crime analysis. If an offender's perceived risks of crime increase, so much the better.

Crime Analysis Implications of Mapping

As a technology tool, GIS will continue to evolve and improve our sensitivity, understanding, identification, and forecasting of reported mappable events (Worrall, 1991). Where crime analysis and law enforcement are concerned, GIS mapping technologies will evolve to equip crime analysts with improved analytical tools and dynamic, near-real-time SMART technology capabilities that include:

(1) *More sensitive monitoring* of demographic, social, economic, ecological and environmental factors and their effect on crime offender and victimization conditions.

(2) *Better understanding of patterns* of criminal offenders and of the complex interactions among place, time, offender, victim, and opportunity.

(3) *More accurate forecasting* of changing needs of law enforcement through more precise situation assessments.

(4) *More precise identification* of spatial variations in crime conditions as a basis of targeting resources for intervention.

(5) *More rigorous identification* of crime targets and magnets, which will promote local services in needed areas and reduce the expense of programming in unneeded areas.

(6) *More effective and responsive crime service planning,* vehicle tracking, and automated vehicle dispatch through more accurate identification of the determining factors of crime and expert forecasting of the changing patterns of crime, enabling operations to reflect changing needs.

(7) *Improving the quality of law enforcement service* management by developing more economical approaches for undertaking routine activities through more efficient scheduling.

(8) *Improving the cost-effectiveness of asset management* by developing more accurate asset disbursement, tracking, monitoring, and mapping in near-real time or real-time conditions.

(9) *Improving law enforcement planning processes* by developing means for modeling and simulating alternative scenarios, and by developing techniques to assess the suitability of new proposals.

(10) *Improving law enforcement policy-making processes* by developing more sensitive methods for evaluation and analysis of policies and programs.

SMART mapping technologies are evolving quickly, rapidly becoming even smarter. The integration of SMART technologies in law enforcement settings will set a new benchmark for policing and crime analysis. While caveats and other considerations should be reviewed on a departmental basis, the potential improvements to crime analysis, police response time, officer safety, and specific deterrence provided by SMART technologies are worth considering for nearly all mid-to-large size law enforcement agencies.

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NOTES

1. Clarke (1992), in *Situational Crime Prevention,* defines primary situational crime prevention objectives as: (1) increasing offender effort needed to commit crimes; (2) increasing offender risks associated with crime; (3) reducing rewards of crime. Subsequently, a fourth objective has been added, namely, (4) removing excuses for non-performance.

2. As this entire volume is dedicated to GIS, the reader is referred to the introductory chapter and internet sources (http://www.gisworld.com) for more information on GIS systems.

3. Ray Sanford, "GIS User Agencies," survey of International Association of Crime Analysts" members, Winter, 1996. Contact, rsanford@community.net for more information.

4. The Incident-Based Reporting Project Advisory Board conducted a survey of current and potential uses for incident based data and identified fourteen applications (Coyle, Schaff, and Coldren, 1991).

5. Visualization of 2-D illustration is a modified example of an interpolation illustration provided in *MathCad's Mathsoft* Handbook, 1991.

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Appendix: Comprehensive Listing of Potential Uses of Mapping in Crime Analysis

The following list was prepared after culling through volumes of articles on mapping, geography, criminology, and crime analysis.

Each of the items listed represent potential mappable features or analysis presently or potentially predictable using mapping. The integration of GPS and GIS technologies will expedite the onset of use of these technologies in law enforcement generally and in crime analysis particularly.

Beats and redistricting

Before-and-after intervention analysis

Building structure, zoning, occupancy, vacancy

Calls for police assistance

CAP indexing of crime risk reduction

Catchment areas analysis

Community policing resources tracking

Change in contacts

Crime magnets identification

Crime pattern analysis

Crime prevention through environmental design

Diffusion

Dispatch

Dispersion

Displacement

Domestic dispute calls

Drug enforcement outpost location mapping

Drug market analysis

Emergency response planning

Extremes and outliers identification

Feature identification (abandoned autos, buildings, and drug incidents)

First abuse or offense analysis

Functional displacement

Gang territory and disputed space

Geographic displacement

Geographic profiling

Health sites and health risk hot spots

Homeomorphic vs. geometric space analysis

Hot clusters

Hot-spot areas

Hot-spot ellipses

Intertemporal comparisons

Journey to crime analysis

Lighting surveys

Location of lattice points

Location of new nodes

Magnet identification

Major landmarks

Mobility pattern analysis

Offender flexibility, mobility, and opportunity

Offender movement patterns

Patrol method optimization

Proximity

Public housing and public parks

Radial (buffering) searches

Safehouse location mapping

Scale and perception of clusters

Serial pattern recognition

Spatial autocorrelation

Spatial behavior of offenders by type

Special event planning (e.g., concerts, parades, holidays)

STAC hot-spot analysis

Street-gang-related incidents

Structure type and purpose

Tactical displacement

Tactical early warning system

Target displacement

Temporal displacement

Terminal and transportation crime risk

Testing the accuracy of cognitive maps

Use of space analysis

Topological transformations

Zoning and redistricting