NATIONAL CRIME MAPPING SYSTEM

Based on Geographic Information Systems Technology and
Uniform Crime Reporting/National Incident-Based
Reporting System Data

by

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1. Introduction

On May 16-17, 1994 the National Institute of Justice held a conference entitled "Mapping Crime in the 21st Century." Invited were representatives of over 30 municipal or county police departments; over 30 officials from the U.S. Department of Justice, National Institute of Justice, Bureau of Justice Assistance, and Bureau of Justice Statistics; and several university researchers.

The primary purpose of the conference was to gather information on the feasibility of building a national crime mapping system for the Attorney General's office and associated federal agencies (e.g., FBI, DEA, ATF, and BJS). The envisioned system, based on geographic information system (GIS) technology, would collect data from cities and counties around the country and provide real-time monitoring of crime trends and patterns.

The conference was successful in addressing several technical, organizational, and policy issues associated with building such a system. The purpose of this paper is to follow up on the initiative and present a rationale and design for a National Crime Mapping System (NCMS). The system would have two components:

- **National-level**: using available Uniform Crime Reporting (UCR) data and providing national, regional, and state maps with crime and explanatory (e.g. socio-economic) statistics displayed by county (completed in year 1) and

- **Jurisdiction-level**: using National Incident-Based
Reporting System (NIBRS) data from a representative sample of cities/counties and providing city/county maps with crime and explanatory information displayed by census tract or as points ("pins") on streets (system completed in year 2).

The national-level system would provide an overall crime assessment for the country and within states, while the jurisdiction-level system would provide in-depth and detailed "blow-ups" for an index set of cities/counties. The national-level system is feasible now, except for speeding up UCR data submissions to the FBI for timeliness. The jurisdiction-level system can be phased in, jurisdiction-by-jurisdiction, until a representative sample of cities is available for generalization of patterns observed to other parts of the country.

The NIBRS database design needs to be augmented with incident location data. Initially NIBRS-compliant data may be able to be obtained directly from DMAP and other jurisdictions that currently have GIS capabilities. Finally, note that the jurisdictional-level system will be available for implementation by jurisdictions. This will be facilitated by using the NIBRS file structure as the import or attachment format for the jurisdiction-level GIS. Hence if jurisdictions would prepare NIBRS data for submission to the FBI, they would also get our GIS crime analysis package as a by-product— an incentive for submitting NIBRS data. Such incentives were often the topic of discussion at the conference.
2. System Objectives

A map-based crime monitoring system should provide data to assess crime trends and patterns in the country as a whole and across regions, states, counties, cities, and small areas within counties and cities such as census tracts and on streets. Map displays of data should quickly provide clear understandings of complex phenomena.

One approach to determining specific objectives for the NCMS is to consider planning needs of various length horizons:

- **Current**: most recent month’s data
- **Short term**: one to 12 months
- **Medium term**: one to three years
- **Long term**: three to five or more years.

For the current and short term, monitoring has the primary purposes of assessing current status and extrapolating likely future levels of crime. Short-term quantities of primary use in private sector monitoring systems (e.g., for inventory and sales management, see Makridakis and Wheelwright 1989) and for the NCMS as well are:

- **Current level**: the most recent month’s data or (better) the seasonally-adjusted, smoothed mean for an observational unit (e.g., county or census tract).
• **Time trend change**: the most recent monthly change at an observational unit or seasonally-adjusted, smoothed monthly change.

• **Seasonality**: factors accounting, e.g., for expected summer month highs and winter month lows.

• **Structural or cyclical changes**: abrupt changes caused by special events, economic cycles, etc.

The current level provides the current state of the system and, if smoothed and seasonally adjusted, a reliable basis for short-term forecasting. Time trend change is the major ingredient for early warning systems and, along with the current level and seasonal adjustments, the basis for short-term forecasts. Finally, structural changes--recorded and shared in special event databases (see Gorr 1986a, 1986b)--explain abrupt changes in data patterns, thereby allowing for informed data uses by centralized analysts who are otherwise not experts in local conditions.

Immediate and short-term crime analysis needs based on such quantities include:

• **Hot spot analysis**: identify and track high crime areas,

• **Early warning system**: identify changes in crime levels and the emergence of crime waves,
• **Seasonal adjustment:** adjust crime data for expected seasonal variations to more accurately gauge changes,

• **Short-term forecasts:** extrapolate crime trends,

• **Counterfactuals:** provide extrapolative forecasts as a baseline for evaluating short-term impacts of policies and environmental changes, and

• **Special event analysis:** track responses to major events (e.g., Rodney King's beating and trial).

Medium and long-term studies generally have the purposes of informing policy making and carrying out program evaluations. Such studies must include theoretical modeling and explanatory variables to control for confounding variables and to decompose overall crime patterns into components affected by policies. Natural experiments, such as innovative police programs implemented in some cities but not others, provide opportunities for evaluation. The NCMS could provide data on experimental and matching cities. The latter data, identified using demographic and other explanatory variables, serve as controls for time series analyses.

The next section briefly reviews two literatures that provide guidance for collecting and analyzing spatio/temporal crime data and explanatory variables.
3. Theoretical Foundations

3.1 Ecology of Crime

The early ecology of crime studies, starting with Clifford Shaw's seminal study of delinquency in Chicago (1929), tended to be descriptive, noting the concentration of crime in central business districts. Concentrations of delinquents' residences varied inversely in proportion to distance from the city center. Delinquents were also located adjacent to heavy industry and commerce. Attending socio-economic conditions were areas that tended to have physical deterioration, decreasing population, poverty, minorities, and immigrant populations.

Schmid (1960) found similar patterns in Seattle, but also found crime pocketed in certain areas, like "skid row." Robbers commit robberies in central business districts far from their residences. Robber offender characteristics included male unemployment, lower number of school grades completed, lower median income, and fewer people 14-and-over unmarried. Low family and economic status were highly correlated with robbery, larceny, and auto theft. Family instability was an important factor contributing to delinquency. Lander (1954) found evidence that the percentage of non-owner-occupied housing and percentage of nonwhite population was associated with delinquency. Nonwhites were

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1Material in this section borrows heavily from Cohen, Gorr, and Olligschlaeger (1993).
correlated with low socioeconomic and family status, so that poverty is the causal factor for crime. Additionally, the criminal career literature (e.g., Blumstein, Cohen, and Farrington 1988, Blumstein and Cohen 1987) finds that there is an at-risk age group, more likely to commit crimes.

More recently there have been studies providing theories on the ecology of crime. Routine activities theory, due to Cohen and Felson 1979, states that criminal events result from motivated offenders, suitable targets, an absence of capable guardians against crime, and a converging of offenders and victims nonrandomly in time and space. Related literatures studied factors affecting motivated offenders, opportunity of availability of targets, lifestyles of victims, and deterrent effects of official and unofficial policing implied by guardianship.

Sherman et al. (1989) was the first paper to test routine activity theory with spatial data. Using 911 call data, this paper found substantial concentrations of police calls in relatively few "hot spots." Geographers have long recognized day-to-day clustering of people residing over wide areas into small nodes of activity (Brantingham and Brantingham 1984). This is consistent with drug dealing observed in Pittsburgh. Gorr and Olligschlaeger (1994), using Pittsburgh DMAP data, found that the eleven open-air drug markets of Pittsburgh are, for the most part, located in areas with high percentages of black population (over 85% black). These drug markets, however, cover only somewhat more than half the total area with high black populations, so that there are factors other
than poverty and race at work. See Exhibits 1 and 2 below.

Roncek and Maier (1991) found the number of taverns and lounges in city blocks in Cleveland positively associated with index crimes. Taverns' influence on crime was compounded when the taverns were located in areas with more anonymity and lower guardianship. Cohen, Gorr, and Olligschlaeger (1993) applied routine activity theory to illicit drug markets, recognizing the tacit coordination required of dealers and buyers for drug transactions. It was found that public land uses with low guardianship--such as run-down commercial strips, bars, and public housing projects with high proportions of female-headed households--are primary candidates for open-air drug markets.

In summary, the ecology of crime literature suggests several factors relevant to choosing explanatory variables for crime over geographic dimensions. In overly-simplified but succinct terms: crime can expected to be concentrated in "hot spots" in areas with poverty and low guardianship.

3.2 Spatial Diffusion Modeling:

the assertions need to be validated.

Crime "innovations" (e.g., car jackings and drive-by shootings), like new communicable diseases, may start in random locations, but take hold in "crime epicenters"—large and densely populated cities with significant poverty, large immigrant populations, subcultures, dense transportation networks, and other conditions conducive to the growth and spread of crime. Once in an epicenter, an innovation follows an S-curve growth pattern. It spreads slowly at first, but then passes into an exponential growth phase. It seeps out to adjacent areas, like "wine spilled on a table cloth" through contagion. Suburbs and adjacent cities become "infected" with some delay, and have less intense growth because conditions are not as favorable for crime as in the epicenter.

U.S. cities are connected by heavily traveled, long-distance transportation networks—airline routes, railways, and interstate highways. This network, plus conditions such as coastal versus inland locations and ranges in city size from large to small, give rise to an "urban hierarchy." Negative innovations spread hierarchically (and with delays) from epicenters to second-tier cities, and later from epicenter and second-tier cities to third-tier cities, etc. For example, a drug epidemic that starts in New York City, Miami, and Los Angeles may materialize next in Boston, Houston, Philadelphia, Chicago, Detroit, and other secondary cities; and still later in Kansas City, Pittsburgh, Phoenix, Atlanta, etc. See Exhibits 3 and 4 below for examples of AIDS/HIV contagion and hierarchical diffusion.
Crime growth rates tend to be largest in the epicenters and decrease as one descends the urban hierarchy due to decreasing conditions favorable for growth and spread. Golub, Gorr, and Gould (1993) showed, however, that "continued seeding" of "infections" through contacts with epicenters may dramatically increase secondary and tertiary growth rates during exponential growth phases. Hence it may be critically important to find interventions to curb hierarchical contacts and transmissions. Small changes in exponential growth rates greatly affect overall infection levels.

There are potentially several opportunities for police enforcement and prevention provided by monitoring for crime epidemics:

- **It may be possible to identify crime waves at their earliest stages.** For example, it may be possible to build a network of intelligence officers in potential crime epicenter cities to detect crime innovations. Once detected, an innovation may be slowed or perhaps eliminated. The NCMS would allow tracking, regardless of outcome.

- **Delays inherent in hierarchical spread may provide time for "downstream" cities to implement preventive measures.** It may be possible to prevent or slow diffusion to second tier and other cities. If diffusion pathways can be identified, interdiction may be possible. Also,
downstream cities may have time to prepare for and prevent or minimize impending crime waves.

- *Detailed studies within counties and cities may allow evaluation of police interventions to stem crime waves.* As natural experiments arise, due to variations in local responses to crime waves, it may be possible to analyze "before and after" data, including control cities.

4. Databases

4.1 *Crime Indicators*

Offense data are useful measures for crimes against persons and property because victims have strong incentives to report offenses and furthermore there are several other ways that offenses come to the attention of police. Offense data suffer from an undercount bias, however, for crimes with low solvability factors (e.g., Sherman et al. 1989). A much larger undercounting bias exists in arrest data for crimes against society (e.g., drugs, pornography, gambling, and prostitution) as there are no victims to report offenses. While arrest counts may be correlated positively with the levels of such crimes, they remain more an indicator of limited police resources allocations.

Sherman et al. (1989) has called for the increased use of 911
call for service data to remedy these limitations, but as of yet there do not exist national standards defining call nature codes. Furthermore, there likely exists substantial variation in call-taking protocols and caller behaviors that may influence counts and interpretations. Hence, the best crime indicators available are offense counts for crimes against persons and property and arrest counts for crimes against society.

It is essential for the NCMS to compare crime levels and changes across jurisdictions. The UCR and partially implemented NIBRS of course provide national standards for offense and arrest data coding, collection, and submission. UCR and NIBRS data are thus essential for the NCMS.

4.2 UCR Data

Nearly 16,000 law enforcement agencies nationwide provide monthly UCR reports to the FBI, classified into eight index crimes and scored to jurisdiction-wide offense, arrest, and clearance counts. Also provided are supplemental aggregate statistics for fair market values of stolen property by ten property classes and by crime classification; age, sex, and race categories of arrested persons for Part I and II offenses and for murder victims; weapon type used, relationship of murderer and victim, and circumstances for murders; and number of officers killed or assaulted by weapon type and type of activity (see U.S. Department of Justice, 1984).
These data have several well-known limitations. In particular, the "hierarchy rule" for classifying multiple-offense incidents counts only the highest index offense, thereby undercounting lower offenses. Also, only scored (aggregate) data are provided, and only at the jurisdiction level. Nevertheless, UCR data are useful at the national and state scales of analysis for variations by county and city. They can depict overall crime levels and changes at these scales.

Monthly UCR data are available on magnetic tape or cartridge for all tables and variables collected, starting in 1960. One complication is that jurisdictions are not identified by FIPS code, so that some effort is needed to connect UCR data to Census Bureau map files for counties and cities.

4.3 NIBRS Data

Starting in the late 1970s, the FBI conducted extensive studies to design NIBRS to remedy UCR limitations and bring uniform crime reporting into the computer age. NIBRS has several extensions and virtues over traditional UCR data, including:

- **Incident-based reporting**: related data for 52 attributes of offenses/arrests, property stolen/recovered, victims, offenders, and arrestees are available for each incident. Hence data can be aggregated by any combination of
categories desired and time periods based on the full related set of available attributes.

- **Full reporting of multiple-offense incidents:** up to 10 crime types can be recorded per incident.

- **Expanded set of crime types:** a total of 57 distinct group "A" and "B" offenses are used (compared to 29 Part I and II UCR crimes).

- **Continuous variables:** for age and other quantities instead of categories.

- **Additional codes:** new codes for 24 location types (e.g., Bar/Night Club, Liquor Store, Highway/Road/Alley), expanded weapons codes including designation for automatic handguns and rifles; Type Criminal Activity (e.g., Distributing/Selling, Cultivating/Manufacturing/Publishing) for selected crime types; 39 property types (e.g., Computer Hardware/Software, Firearms); individual drug types; Aggravated Assault/Homicide Circumstances (e.g., Gangland, Juvenile Gang); Relationship of Victim to Offender(s) codes (e.g., Victim was Spouse, Victim was Stranger), etc.

The detailed classification of related incident data makes NIBRS an
extremely valuable database for NCMS. Some examples that illustrate query possibilities from NIBRS data include:

- Aggravated assault/homicides where the arrestee was a juvenile, used an automatic weapon, and the victim was a juvenile stranger.

- Robbery offenses inside or outside of Bars/Night Clubs by male offenders between the ages of 18 and 24 who were suspected of being drug users.

- Car jackings (assault and vehicle theft at highway/road/alley location).

- Cocaine drug arrests at Air/Bus/Train Terminals.

One enhancement to NIBRS needed to support GIS processing are incident locations, which need to be added to Administrative Segment "A" records for offenses and to "B" arrests records. Two types of location data, coded directly by jurisdictions supplying data, are desirable: latitude/longitude coordinates and census tract numbers.

To facilitate the generation and recording of such data, our jurisdiction-level NCMS component would be available for direct use by jurisdictions. Indeed, the availability of such a system is an incentive for a jurisdiction to submit NIBRS data to the FBI. The
record formats for input to the jurisdiction-level GIS will be the same as required for NIBRS submission.

Also, on an interim basis, police officers could directly code census tracts on offense and arrest reports (e.g., the Pittsburgh Police already do so). The resulting geographic resolution would allow for detailed studies by census tract within cities and counties; e.g., see Exhibits 1, 2, and 5 below.

4.4 Crime Data Availability and NCMS Staging

The NCMS needs to build first on available UCR data, but be able to phase in NIBRS data on a jurisdiction by jurisdiction basis. Since it is possible to aggregate selected NIBRS data to produce equivalent traditional UCR data, it is natural to maintain UCR data and outputs for the entire U.S. over the foreseeable future, and to provide additional NIBRS incident-based information as a supplement where available.

One strategy would be to place a high priority on implementing all major crime epicenters and a sample of second-tier and third-tier cities on NIBRS (with incident location coordinates) and in the NCMS to provide detailed policy-level information. A representative sample would be sufficient for policy making, since generalizations could be made for the entire country.

Clearly, the starting place is with cities that currently or shortly will have crime mapping and GIS capabilities. Several
cities and counties across the country---e.g., Baltimore, Jersey City, San Diego, Tacoma, Los Angeles, Pittsburgh---have crime mapping capabilities, using GIS technology. It is very likely that offense and arrest crime codes used in these systems conform to NIBRS standards. Hence it should be possible, in theory, to collect or produce NIBRS compliant data for selected variables from several locations in the near future. This option is attractive in the short-run, prior to making arrangements for NIBRS data to include incident location data.

4.5 Explanatory Variable Data

Census data by state, county, census tract, and census block group provide social/economic indicators for analyzing crime data. Supplemental indicator data available on an annual or monthly basis are desirable to match collection rates of the crime data. Possible variables include births and deaths, school-age populations, motor vehicle registrations, etc. which are commonly used to estimate county populations in noncensus years. It would be beneficial to identify additional variables and data indicating land uses, especially in regard to low informal guardianship and poverty.
5. National Crime Mapping

While complex and requiring significant effort, we assume that data import/attachment programs, query criteria selection forms, tabular reports, and other standard information system components can be readily designed and implemented on an appropriate computer platform for the NCMS. We will concentrate here only on map-based outputs needed for the NCMS.

5.1 National-Level Component

We suggest obtaining samples of UCR monthly data and producing a series of illustrative map displays as a basis for designing the national-level NCMS outputs. Several map types are available for displaying data across large areas, such as the continental U.S., major regions, or states:

- **Area (choropleth) maps**: display nominal class variables by color and shading intensity by areal unit. For maps covering the entire U.S., the natural areal units are states and counties. For cities or counties, census tracts are useful. Exhibits 1 and 2 are choropleth maps from the Pittsburgh DMAP, showing that 911 drug call data correlate with percentage black population. Exhibit 5 is another example, showing change.
Shaded Isoline maps: use interpolation procedures to produce smooth contours or elevations and include shadings of texture or color to create a strong visual effect. Such maps are effective for displaying city and county data at the national or regional levels. Exhibits 3 and 4 are samples from Gould (1993) showing the spatial diffusion of AIDS at the national level. National choropleth maps using all 3,000 plus counties are too detailed and cluttered by county boundaries. Isoline maps minimize "ink" while maximizing relevant information at the national or regional level. Three-dimensional maps are another alternative, and while visually impressive, obscure information because they must be drawn in oblique view. The vantage point taken for viewing is critical to their appearance.

Proportional point markers: Suppose that we wish to display data for a selected set of cities across a large region or the country. Cities are too small in area to be represented by their boundaries at this scale. A map using point markers (e.g., circles, squares, etc.) with area proportional to variable magnitude can be used. Cities may be labeled with their names and coded by marker shape or color to show size or position in the urban hierarchy. Proportional point markers are also essential for accurately portraying traditional police
Pittsburgh DMAP, and is a blow up of a high weapons calls increase area 2 identified in Exhibit 5. Note that the curved streets and long buildings in Exhibit 6 are in a public housing development, and clearly the locations for the highest numbers of weapons calls.

Also several map arrangements may be valuable for analyses:

- **Side-by-side maps**: for before and after studies, for comparing crime patterns with social/economic patterns, etc. (e.g. see Exhibits 1 and 2).

- **Map time series**: maps of the same variable for successive time periods on the same sheet (e.g., four most recent quarters). Such maps are effective for displaying spatial diffusion (e.g., as in Exhibits 3 and 4).

- **Early Warning System maps**: use change data or estimates to highlight recent large increases or decreases in a variable. Accompanying level maps are blow-up, small scale maps of highlighted regions (e.g., see Exhibits 5 and 6 from the Pittsburgh Early Warning System).

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Note that the original map in Exhibit 5 uses blue shading to identify reductions (cooling off) and red for increases (heating up). The four areas highlighted in boxes are in the set of heating up areas.
5.2 Jurisdiction-Level Component

We also suggest obtaining a sample of NIBRS data to structure database files for the jurisdiction component of the NCMS. If necessary, it would be possible to initially add hypothetical incident locations to the NIBRS sample in order to provide test data for completing the NCMS design, and later add real locations when/if available. Then it would be possible to implement the Pittsburgh DMAP mapping capabilities and any other capabilities identified as desirable as the stand-alone jurisdiction-level component. Use by federal policy analysts would be through a menu displaying available cities, which would then access a selected city stored as a separate database and GIS.

We suggest further to make summary NIBRS data, aggregated by jurisdiction, available to the national-level component of the NCMS for plotting, using proportional point markers. If at some time in the future the country converts to NIBRS data on a large scale, then detailed NIBRS data summaries can replace UCR data.

6. Conclusion

We believe that a National Crime Mapping System is feasible and would be valuable for developing effective crime policies in this country. We believe that fundamental discoveries will be made on crime patterns through the use of NCMS data and mapping. Also,
new comparative analyses across cities, and especially the identification and tracking of crime waves (i.e., the spatial diffusion of crime), will provide new tools and opportunities to combat crime in the U.S.

Critically important for implementation would be 1) speeding up submission of monthly UCR data to the FBI and 2) prioritized implementation of NIBRS to provide a representative sample of cities and counties with highly detailed incident data. One task to carry out is to develop NIBRS standards for incident location data, which need to be added to the existing NIBRS database design.

It should be possible to implement the NCMS in phases over a two year period. The full implementation of a representative sample of cities with NIBRS data will take considerably longer.
6. Approach and Milestones

References


Exhibit 1

Choropleth Map of 911 Drug Calls per 1,000 Population for 1991. Areal units are 1990 census tracts and drug market areas are denoted PH for public housing and CR for mixed commercial/residential land uses.

Exhibit 2

**Exhibit 3**

The AIDS surface over the continental United States in 1984. Although still in what has been termed the "seeding stage," the geographical effects of hierarchical and spatially contagious diffusion are already quite clear.

**Exhibit 4**

The AIDS surface over the continental United States in 1988. Major north-south alignments on both the east and west coast have intensified.
Exhibit 5

Area Map of Change in Number of Gun Calls by Census Tract from Three Months April-June, 1993 to Next Three Months July-September, 1993 (Increases Larger than Tract Mean are Colored Red)

Pittsburgh Bureau of Police - Crime Analysis Division 4/12/94. A DMAP Product

Changes in Weapon Related Calls for Service

From Period (4/93 - 6/93) to Period (7/93 - 9/93)

Scale: 7714 sq/inch