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FROM UNSOLVED CRIME NUMBERS TO OTHER FORENSIC STATISTICS: OPOLE POLICE DEPARTMENT'S OBSERVATIONS USING BAYESIAN MODELING

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1. BACKGROUND

Not all crimes are solved, and some crimes are not even detected. Such a reality for any police department, in any part of the world, is a challenging one. Moreover, the main function of the police, as empowered by the state, is to enforce the law in order to ensure the safety, the health, and the possessions of its citizens, and to prevent crime and civil disorder from breaking out. Therefore, statistical observations through Bayesian spatio-temporal modeling as regards to unsolved crime numbers and probability measurements from detected to undetected cases will prove useful in overcoming such challenges faced by the police department in Opole, Poland, and elsewhere for that matter.

It is important to note that from a motivated offender's point of view that the most suitable opportunity to commit an offense is one in which the perceived risk of detection is low, where committing the offense requires little anticipated effort, and also that when completing the offense the delivery of the desired reward is likely.[1] Hence, many violations of legal statutes and regulations remain undetected.[2] In fact it can be sensibly argued that individuals and firms commit violations in the hope of escaping detection. Fewer, if any violations would be committed if detection was perfect. Therefore, any improvements to detection rates from a lower level to

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[1] D. Cornish, R. Clarke, *The Reasoning Criminal: Rational Choice Perspectives on Offending*, New York 1986.

[2] J. Feinstein, Detection Controlled Estimation, *The Journal of Law & Economics* 1990, 33 (1), pp. 233–276.

a higher level are a must for police departments in order to, not only improve crime detection, but also to function as a deterrent for those offenders and whatever their motivations may be. Such expectations are difficult to meet and it is impossible to determine with accuracy the amount of crime in any given jurisdiction at any particular time.[3] But the failure to detect all violations substantially complicates the statistical analysis of illegitimate activities and regulatory noncompliance, because individuals whose violations remain undetected (and unrecorded in the data) are misclassified as compliant. Unfortunately, a large proportion of the crimes committed including serious delinquency go undetected by the police.[4]

Besides, figures from a plethora of crimes suggest clearance and detection rates have not improved. Even, according to the Bureau of Justice Statistics, in 2015 in the U.S., only 62% of murders and non-negligent homicides in the U.S. were cleared.[5]

It appears that most murders go unsolved in many U.S. cities, for example, in Columbus, Ohio, in 2017 the police only managed to clear 34% of the city's homicides.[6]

But it is not only the U.S. which experiences this kind of phenomena as regards to unsolved or undetected crimes. A large scale study conducted in Germany in the 1990s estimated that 50% of murders go undetected.[7] Whereas, other shocking crimes such as sex offences or the killings of elderly people suggest that there is a lot of effort to be done in order to improve detection rates and solve crimes. For example, Neutze et al.[8] show that 57% of the total sex offenders have never been detected by the criminal justice system, as well as that many of the homicides were committed against older people.[9] But nor is this phenomena always related to such shocking crimes. For example, in the UK more than half of crimes on Scotland's railways go undetected (fortunately, the majority of crimes reported to the British Transport Police result in no injury coming to a victim, and tend to be theft, common assault or vandalism).[10]

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[3] M. Kumar, J. Borbor, Urban Crime: A Sociological Study of Johat Town, *IOSR Journal of Humanities and Social Science* 2018, 23 (4), pp. 53–59.

[4] G. Sweeten, Scaling Criminal Offending, *Journal of Quantitative Criminology* 2012, 28 (3), pp. 533–557.

[5] J. Gramlich, *Most Violent and Property Crimes in the U.S. Go Unsolved*, Pew Research Center, 2017, https://www.pewresearch.org/fact-tank/2017/03/01/most-violent-and-property-crimes-in-the-u-s-go-unsolved/ (access: 04.12.2021).

[6] Crime and Justice News, *Most murders go unsolved in many cities*, The Crime Report, John Jay College of Criminal Justice, 2017, https://thecrimereport.org/2017/08/16/most-murders-go-unsolved-in-many-cities/ (access: 04.12.2021).

[7] A. Baranowski et al., The CSI-education Effect: Do Potential Criminals Benefit From Forensic TV Series?, *International Journal of Law, Crime, and Justice* 2017, 52, pp. 86–97.

[8] J. Neutze et al., Undetected and Detected Child Sexual Abuse and Child Pornography Offenders, *International Journal of Law and Psychiatry* 2012, 35 (3), pp. 168–175.

[9] J. Hupp, *Crimes Against Older Adults: Perspectives of Student and Police Detectives*, A Thesis Submitted to the Faculty of Miami University in partial fulfillment of the requirements for the degree of Master of Gerontological Studies Department of Sociology and Gerontology, Miami University, Oxford 2006, OH, USA.

[10] C. McCall, *More Than Half of Crimes on Scotland's Railways Go Undetected. The Scotsman*, 2019, https://www.scotsman.com/news/transport/more-halfcrimes-scotlands-railways-go-undetected-1414683 (access: 04.12.2021).

Directly, as regards financial matters, Crofts[11] claims that approximately 60% of gambling related crimes remain unsolved, while a historic example from California by Higgins[12] may help to put the importance of this issue into greater perspective when in 1974 the estimated costs of the crimes of early minor offenders, which included taking undetected crimes into account, revealed that the costs are about 11 times that of detected times, or approximately $930 M.

It is hoped that the brand-new statistical observations herein will prove useful in overcoming similar challenges faced by the Police Department in Opole, Poland, and elsewhere.

2. AIM OF STUDY

In this study, we evaluated 2015–2019 spatio-temporal patterns of undetected territorial crime rates and their annual five-year growth rates (all categories combined) based on the reference population using hierarchical Bayesian modeling. Then we compared the combinations ("Types") of these levels (below/above the mean, and negative/positive increments) with the odds of detected to undetected crime numbers. To look even more closely at the relations of undetected crimes, we extend the statistical analysis, additionally, with square area and crude rates of the reported crime statistics per reference population.

3. MATERIAL

The study region is Opole province <10 K km² is located in the southwestern part of Poland, populated by approximately <1 M inhabitants. By the way, Opole province is not recognizable as one of the elite political, economic or educational centers of Poland, and its role in the national perspective is not leading. However, in the recent years some key industrial investments were made in the region, especially in energy (a power plant construction), which has resulted in the employment of an additional external workforce (a few thousand people) of various nationalities.

Information on detected and undetected crime numbers in the region originates from the Opole Provincial Police Headquarters. Statistics Poland was our data source for demography characteristics of population. The basic crime offense data consisted of reported incidents of crime (all categories) reported to the police for 5 years spanning from January 1, 2015 to December 31, 2019 (Table 1).

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[11] P. Crofts, *Researching the Link Between Gambling and Crime*, Paper presented at the Evaluation in Crime and Justice: Trends and Methods Conference convened by the Australian Institute of Criminology in conjunction with the Australian Bureau of Statistics and held in Canberra, 24–25 March 2003, University of Technology, Sydney 2003.

[12] T. Higgins, The Crime Costs of California, *Journal of Research in Crime and Delinquency* 1977, 14, pp. 195–205.

Table 1. Crime and demography in Opolskie province, Poland, in the years 2015–2019 (following the Opole Provincial Police Headquarters)

Year	2015	2016	2017	2018	2019
Crime	27.411	28.063	28.399	24.428	24.702
Population	996.011	993.036	990.069	986.506	982.626

($p>0.05$)

All crime incidents were geocoded to a particular administrative unit (community) and then analyzed in the context of the undetected crime risk and its increment.

4. METHODS

Recognizing the similarity to epidemiological diseases, we first used spatial Bayesian modeling following Bailey[13] as great practical and potential value in the risk analysis of crime. In turn, to build a spatio-temporal increment model, we propose the Bayesian approach suggested by Congdon.[14]

To study the possible background of the established crime variation, the univariate regressions were fitted by a WinBUGS software,[15] which uses algorithms for a Markov Chain Monte Carlo (MCMC) simulation to generate dependent samples from the posterior distribution of the models. Due to its highly parameterized modeling, the models were run for "burn in" for 1,000 iterations and the subsequent 10,000 "production" samples. Here, the performance of MCMC simulation of the Gibbs sampler was diagnosed with the Gelman-Rubin statistic available within WinBUGS software.

In our work, the undetected crime rates and their five-year increments were plotted graphically in choropleth thematic maps. All data and statistical models can be provided upon request.

5. RESULTS

The established estimates of the Bayesian geostatistical models of undetected crime rates and their five-year growths (increments) in the form of local patterns of total crime at the community level for the Opolskie Province, Poland, over the time period 2015–2019 were plotted in Figure 1, Panels A & B, respectively.

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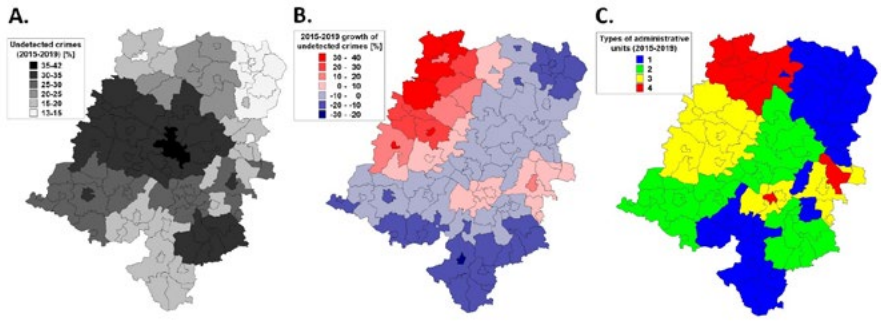
[13] T. Bailey, *An Introduction to Spatial and Spatio-Temporal Modelling of Small Area Disease Rates*, Short course presented at Faculdade de Ciências Médicas, UNICAMP, Campinas, Brazil, 8–10 April, 2008, School of Engineering, Computing and Mathematics, Exeter 2008, UK.

[14] P. Congdon, *Applied Bayesian Modelling*, Chichester 2003, pp. 310–317.

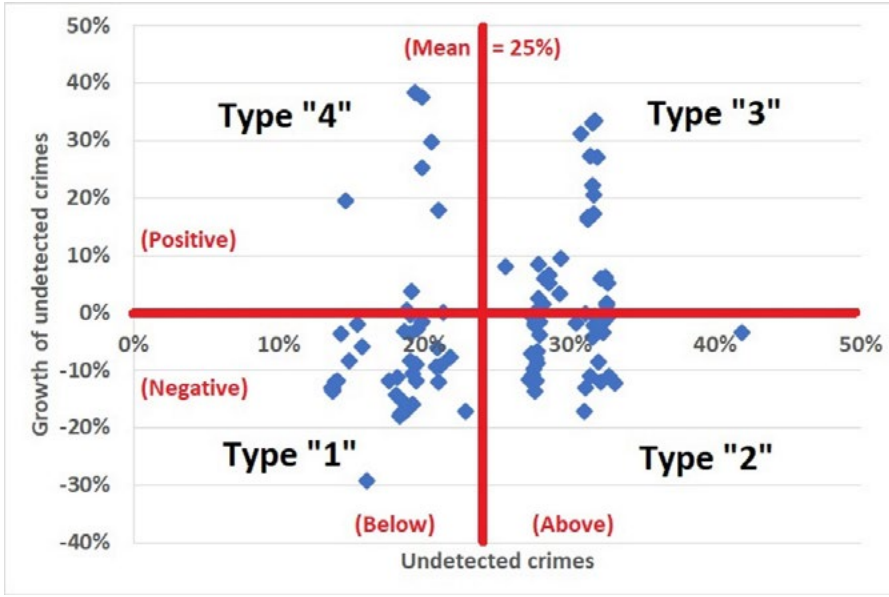
[15] D. Spiegelhalter et al., *WinBUGS Version 1.4.3*, Medical Research Council-Biostatistics Unit, Cambridge 2004, UK.

Figure 1. Bayesian spatio-temporal models of undetected crime rates (Panel A), five-year increments (Panel B), and types of administrative units of crimes (Panel C) in Opolskie province, Poland in 2015–2019 (based on the Opole Provincial Police Headquarters crime statistics)



A graphical plot of the four types of administrative units based on these levels, i.e. below/above the mean of undetected crime rates (=25%), and negative/positive increments is presented in Figure 2.

Figure 2. Types of administrative units following undetected crimes in Opolskie province (2015–2019)



Description:

Type "1" = administrative units with <25% of undetected crime rates and negative undetected crime rates" increment

Type "2" = those units with >25% of undetected crime rates and negative undetected crime rates' growth

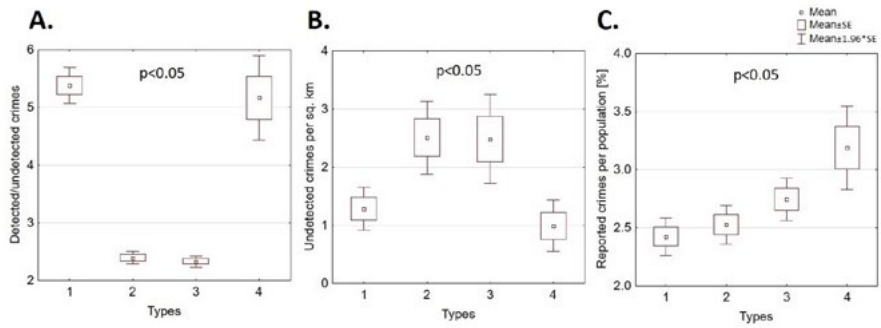
Type "3" = administrative units with >25% crime non-detectable and its positive increment

Type "4" = the remaining option.

For the four determined types of administrative units shown in Figure 2, the thematic map of the undetected crime patterns in Opolskie province (2015–2019) was created (Figure 1, Panel C).

Then, the means of the compared odds of detected to undetected crime numbers in distinguished quarters are shown in Figure 3, Panel A. Additionally, the unsolved crime numbers per square kilometer and reported crime statistics per reference population (crude rates) for determined types of administrative units are plotted in Figure 3, Panels B & C, respectively. Following a one-way analysis of variance, all the differences of means in the last three examples were statistically significant ($p<0.05$).

Figure 3. Analysis of variance of (A) odds of detected to undetected crime numbers in distinguished quarters, (B) unsolved crime numbers per square kilometer, and (C) reported crime statistics per reference population in determined types of administrative units in Opolskie province (2015–2019)



Looking at the results presented in Figure 2, Panel A, interestingly is based on the unsolved crime numbers and reference population (the only numbers used in Bayesian spatio-temporal analysis), and displays that the odds of detected to undetected statistics can be predicted. The proportion of detected/undetected crime numbers >5 were typical for the negative increment of unsolved offenses, while the lowest clearance rate ≈2.5 was found in the types of administrative units with the positive tendency of undetected crime numbers. Analogously, the unsolved crime numbers per square kilometer were the highest (≈2.5) in Types "2" & "3", while the lowest (>1) in Types "1" & "4" (Figure 2, Panel B). However, no analogy with the increment statistics of undetected crimes was found with crude rates of crimes per reference population. The lowest rates of crime (=2.4%) were typical for administrative units with the lower average level of undetected crime numbers (<25%) and its negative

increment (Type "1"), whereas the highest crude rate (=3.2%) were estimated within the communes with the lower average level of unsolved crime cases but with the higher non-detectable tendency (Type "4").

6. DISCUSSION

Despite the enormous development of science and technology in the field of criminology and forensics, we have still not reached a satisfactory level of crime detection. This progress is not being hampered by the main traditions and format of the technical proceedings, which are for example, the recording of people's accounts by interrogating them, or the recording of the appearance of the crime scene (i.e. inspection), all of which are most often based on how the law was managed in the previous century. The basic source for their improvement are methods and forms of police investigations which are constantly evolving.

Nevertheless, all operational activities generate personnel and material costs related to crime detection (in order to identify, arrest and indict the perpetrator of the crime), often requiring the involvement of a larger number of people to carry out a number of additional procedural and out-of-trial activities. From our own many years of experience, we can draw the conclusion that it is the higher financial costs, caused by the need for greater involvement of forces and resources in the detection process, that are the main reason for the increase in the percentage of crimes not being detected by the police.

Undoubtedly, criminals also benefit from technological and information progress and show great creativity in new methods and forms of crime. For example, the authors of the unprecedented statistical analysis comparing crime clearance rates from before and after the introduction of crime scene investigation (CSI), suggest that the forensic TV series may educate potential villains (the clearance rates of serious crimes have seriously dropped after the CSI-series were featured in TV programs). Certainly, other procedural and non-procedural reasons, including police corruption[16] may be related to the increase in the percentage of crimes not detected by these services.

It seems, however, in the context of crime numbers, that the non-detectability of crimes is a big problem for maintaining public and social order, and by reviewing scientific reports on this subject - this problem can even be considered 'shameful' (in our opinion, more research needs to be focused on the so-called 'dark figure', including its regression modeling and statistical assessment of risk factors, rather than the analysis of associations with errors in crime detection). For this reason, we undertook in this study an assessment of this forensic phenomenon using adapted geostatistical methods. Interestingly, even by using simple population and geographic data, a lot of new light can be shed on the investigated regional crime levels.

Thus, by taking into account the absolute numbers of undetected crimes and reference populations, we learned that with Bayesian models, the ratios of actual crime

[16] L. Jaitman, V. Anauati, The Dark Figure of Crime in Latin America and the Caribbean, *Journal of Economics, Race, and Policy* 2020, 3, pp. 76–95.

data detected to undetected can be assessed. See the Bayesian modeling (undetected crimes, reference populations) -> detected crimes/undetected crimes (see figure 3A).

From that above statistical relation it can be stated that the degree of crime detection is directly related to the reference population size (i.e. with the absolute numbers used in statistical modeling as the Poisson denominator). And if so, then the above result indicates an irregularity of police personnel in administrative units.

The present statistical result proves the great cognitive power of Bayesian modeling in forensic research and confirms its effectiveness, not only scientifically, but also practically. In the context of the estimated forensic indicators of the number of undetected crimes per unit of territorial area (Figure 3B), it is difficult to speak of its scientific significance for the time being (because we have not found similar incidences anywhere in the literature), however, they may be the subject of further research and assessment of their criminological objective significance.

We were also surprised by the latest result concerning the crude rates of crimes (in reference populations) after modeling the number of undetected crimes (Figure 3C). Although it would seem that the highest level of registered crime should concern the sub-regions with the highest percentage of undetected crimes and their annual increase, this suggestion turned out to be false in the light of the statistical results obtained by us. Our estimates indicate that the highest rates of crime are related to administrative units with a relatively lower level of undetected crimes, and with a higher annual increase. This result indicates the greater importance of temporal rather than territorial changes in the crime rates.

Additional information can be drawn from our analysis. Numerically, the size of the police personnel should be proportional to the number of inhabitants. Since the ratio of detected to undetected crimes does not correspond to the ratio of the reported crimes per population (compare graphs A and C in Figure 3), it can be concluded that there is an inadequate staffing of the reference populations.

Finally, the last and previous statistical results would not be possible without the use of advanced Bayesian modeling procedures, which require the cooperation of statisticians and policemen alike.

7. CONCLUSIONS

The use of Bayesian methods (despite the fact that they are statistically advanced, is simple in a computer application) allows for the unfolding of geostatistical data (regardless of the type) and new possibilities of scientific inference. In our study, we realized of the great cognitive value of undetected crime statistics in criminological analyzes. Thus, we argue that the degree of crime detection is directly related to the reference population size (i.e. with the absolute numbers), and such a result may indicate about an inconsistency of police personnel in administrative units. Then, the influence of the area of administrative territories on the undetected crime numbers may be evident (although not justified by us so far). Finally, for overall crime rates, fluctuations in time within territorial units themselves are more important than differences between them. All these statistical results are quite easy to achieve

with the current programming technique, nevertheless they require the cooperation of interested professional forensic and statistical bodies and further scientific explanations. Finally, it is worth emphasizing that Bayesian methods allow brand-new cognitive horizons to be opened in forensic research.

List of abbreviations

CSI – crime scene investigation
MCMC – Markov chain Monte Carlo

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FROM UNSOLVED CRIME NUMBERS TO OTHER FORENSIC STATISTICS: OPOLE POLICE DEPARTMENT'S OBSERVATIONS USING BAYESIAN MODELING

Summary
The non-detectability of crimes is a big problem for maintaining public order, and by reviewing scientific reports on this subject it seems that this problem can even be considered 'shameful'. For this reason, we undertook in this study an assessment of this forensic phenomenon adapting modern geostatistical methods. This study uses all reported incidences of crimes to the Opole Provincial Police Headquarters committed in the Opole region over a five year period 2015–2019. Spatio-temporal patterns of undetected crime rates were built. Their annual five-year growth rates are based on the reference population using hierarchical Bayesian modeling. The combinations of these levels were compared with the odds of detected to undetected crime numbers. The statistical analysis was extended with square area and crude rates of the reported crime statistics per reference population. We found that the degree of crime detection is directly related to the reference population size which may also suggest the validity of a detailed analysis in terms of adjusting the appropriate staffing of police personnel in administrative units. Furthermore, the influence of the area of administrative territories on the number of undetected crimes was also evident. Additionally, overall reported crime rates and the fluctuations in time within territorial units themselves implicated more important changes in criminal statistics than the differences between them and were established using unsolved crime statistics only. The use of Bayesian methods (despite the fact that they are statistically advanced, is simple in a computer application) allows for the unfolding of geostatistical data (regardless of the type) and new possibilities of scientific inference. All these statistical results are quite easy to achieve with the current programming technique, nevertheless they require the cooperation of interested professional forensic and statistical bodies and further scientific explanations. Finally, it is worth emphasizing that Bayesian methods allow brand-new cognitive horizons to be opened in forensic research.

Key words: undetected crimes, Bayesian modeling, crime mapping, forensic statistics

OD LICZBY PRZESTĘPSTW NIEWYKRYTYCH DO INNYCH STATYSTYK KRYMINALNYCH: OBSERWACJE OPOLSKIEJ POLICJI Z WYKORZYSTANIEM MODELI BAYESOWSKICH

Streszczenie
Niewykrywalność przestępstw jest dużym problemem w utrzymaniu porządku publicznego, a analizując doniesienia naukowe na ten temat wydaje się, że go można nawet uznać za „wstydliwy". Z tego powodu w niniejszej pracy podjęliśmy się oceny niniejszego zjawiska kryminalistycznego, dostosowując nowoczesne metody geostatystyczne. W opracowaniu

wykorzystaliśmy wszystkie zgłoszone do Komendy Wojewódzkiej Policji w Opolu przestępstwa popełnione w województwie w okresie pięciu lat 2015–2019 i zbudowaliśmy modele przestrzenno-czasowe wskaźników niewykrytej przestępczości. Ich roczne pięcioletnie stopy wzrostu oparte są na populacji referencyjnej przy użyciu hierarchicznego modelowania bayesowskiego. Kombinacje tych poziomów porównaliśmy z prawdopodobieństwem liczby wykrytych i niewykrytych przestępstw. Analiza statystyczna została rozszerzona o powierzchnię kwadratową i surowe wskaźniki zgłoszonych statystyk przestępczości względem populacji referencyjnej. Stwierdziliśmy, że stopień wykrywalności przestępstw jest bezpośrednio związany z liczebnością populacji referencyjnej, co może również sugerować zasadność przeprowadzenia szczegółowej analizy w zakresie dostosowania odpowiedniej obsady personelu policji w jednostkach administracyjnych. Wyraźny był również wpływ powierzchni jednostek administracyjnych na liczbę niewykrytych przestępstw. Ponadto ogólne wskaźniki zgłaszanej przestępczości oraz wahania w czasie w obrębie samych jednostek terytorialnych implikowały istotniejsze zmiany statystyk kryminalistycznych, niż różnice pomiędzy nimi i zostały ustalone jedynie na podstawie liczby przestępstw niewykrytych. Zastosowanie metod bayesowskich (pomimo statystycznego zaawansowania, jednakże prostej aplikacji komputerowej) pozwala na analizę danych geostatystycznych (niezależnie od rodzaju) i nowe możliwości wnioskowania naukowego. Przy obecnej technice oprogramowania, wszystkie prezentowane wyniki statystyczne są dość łatwe do osiągnięcia, niemniej wymagają współpracy zainteresowanych profesjonalnych organów policyjnych i statystycznych oraz komplementarnych analiz naukowych. Na koniec warto podkreślić, że metody bayesowskie pozwalają na otwarcie zupełnie nowych horyzontów poznawczych w badaniach kryminalistycznych.

Słowa kluczowe: przestępstwa niewykryte, modelowanie bayesowskie, geografia przestępczości, statystyki kryminalistyczne

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