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Bayesian Networks in Law Enforcement

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Abstract

The contemporary challenges of migration, the terrorists hidden in migrating herds, the accelerated mobility, the info-communication and the sophisticated methods used by criminals, the increasing number of criminal cases are pressing for the study and development of new forensic approaches. One kind of interdisciplinary forensic methodology, the evaluation of probabilistic crime evidences, is in the focus of the paper. It leads on from starting the simple subjective probability approach through the composition of the set of evidences till the action oriented dynamic applications.

Presenting a suggestion for the standardisation of probabilistic scales will improve the proper grounding of judgements and through this the legal security. The scaled application of the Bayesian Networks wherein the joint use of probability and graph theory suggest a new possibility to the forensic scientist and practitioners. The solution may be used as an effective tool in case of difficult criminal cases where instant decision is required. The scaled possibilities may have a place in evidence analysis, investigation and in case of series of crimes in predictive estimations. Its application can be reasonable from the extraction of eroding and fading characteristic features of evidences up to the estimation of original condition of cross contaminated exhibits. A further improvement of the method is the application of the Dynamic Bayesian Network. This provides a possibility to intervene directly in the flow of the daily rhythm of law enforcement. The closing section of the paper provides some examples for demonstration purposes.

Keywords: forensic science, criminology, likelihood ratio, probabilistic scales, Bayesian Network, Dynamic Bayesian Network, surveillance theory

Introduction

In addition to conventional crimes, migration and terrorism pose new kinds of challenges to professionals who are responsible for criminal investigations and national defence. The skyrocketing increase in the number of tragic incidents demands speeding up the development

of methodologies and having a broader perspective on these issues. One of these options is adopting probability based thinking and using it in a much broader scope of applications. Dynamic interventions may offer a suboptimal solution to preventing terrorist attacks and mitigating their escalation. From the detection of a criminal act through the entire process of penal proceedings – including the circumstances of penal measures and the drawing of summarized conclusions – to crime prevention, the application of Bayesian subjective probability is entirely warranted. The study uses this systematic approach to examine the application of Bayesian Networks in criminal cases, from forensic science to criminology.

Role of probability in crime – Overview

Between acts in a penal procedure there may be a "cause and effect, condition and expectedness, precedent and consequence" relationship (Herke et al., 2014). All three pairs of concepts carry the assumption of probability. Uncovering the threads of a crime can be linked to a single actual event, and thus application of the Bayesian probability can be reasonable.

Is it possible to deduce an antecedent from a consequence with any degree of certainty if the witness reports lack veracity or if belief in evidence is not strong enough? "Belief" as used in mathematics and game theory refers to a situation where not all the information required for decision making is available but it does not affect the decision (Hirshleifer-Riley, 1998: 25–61.). With some supplementary social philosophical additions, it may even provide a solution for the judicial legal dilemma (Popper, 1997: 145.). A response from an expert witness that suggests uncertainty transfers the responsibility of decision making to the judge who may not have the knowledge that would be necessary to decide on a professional subject. The negative perception of expert witnesses is clearly demonstrated by the following cynical quote that describes the grades of mendacity: "liars, damned liars, and expert witnesses" (Meier, 2008: 4–19.).

Probability, in its criminological sense, is the strength of a fact-finder's belief in the occurrence of a specific event (Taroni et al., 2006: 1.). Reasonable suspicion is not based on evidence but on presumption the strength of which can be visualized by probabilistic scales. The concept of likelihood ratio quantifies the ratio of probabilities of pro and contra arguments based on known evidence. Bayesian Networks provide guidance to decisions based on systemic approaches through correlations between independent but interacting probabilistic pieces of evidence and events.

Areas of applications of Bayesian probability in criminal proceedings

A number of Hungarian criminal experts already published basic studies in the areas of legal application of subjective probability and Bayesian analysis (Katona, 1965; 1990; Király, 1972: 260; Kertész, 1972). In several works that was either co-authored or based on a shared source of inspiration, Tremmel and Fenyvesi drew the attention to the application of the Bayesian method in forensic science (Tremmel, 2006; Tremmel–Fenyvesi, 2005: 80–82.; Fenyvesi, 2014: 140.). Tóth refers to the early stages of the adoption of the "network model" in regard to indirect evidence used in criminal proceedings (Belovics–Tóth, 2015:

131.). It can be proven that beyond criminal proceedings the theory can be put to good use in implementing decisions and in crime prevention plans.

Applications in the law of criminal procedure

Exploration of facts
When information about acts are received, the probability that a criminal act has been committed is evaluated. The answer "yes" in this case refers not to the certainty of learning about the committed crime but about the probability that warrants the decision. This need for decision making arises again during the survey of the scene and investigation. The amount of data and information to be collected is determined by capabilities and organizational policies. It is becoming clear, however, that the rapid and efficient processing of data and evidence produced in huge volumes can be implemented on a probabilistic basis, using big data techniques (Bőgel, 2015).

Demonstration
In producing evidence the prosecution may evaluate data and information that are either indirect or carry some degree of uncertainty, and may use them as appropriate considering their relevance and weight. The prosecutor's expert determines the degree of uncertainties to prove that the strength of the probability values related to pieces of condemning evidence satisfies the expectations related to facts, and therefore they are admissible in court. Defence may assess the validity of probabilistic evaluation of information from a different point of view. It may explore the weak points of the conclusions drawn using the probabilistic network so be re-evaluating connections and furthermore by creating a new connection network (or using different probability values) the admissibility of the persecution's data can be refuted.

Sentence and reasons
A network system filled with information and facts produced in the preparatory phase of a trial could be used to direct the judge's attention to the dubious aspects of the case. Using a Bayesian Network before sentencing can provide an aid with which it is possible to evaluate if all data, arguments, facts, testimonies and depositions will be taken into account with a necessary and sufficient weight in the objective sentence. It is entirely possible that preventing even a single instance of miscarriage of justice would offset the expense of introducing the system. Adopting the concept of probabilistic evidence poses the greatest challenge in the courtroom (Muller, 2012) as demonstrated by a number of examples that are independent of legal systems and cultures. There were even opinions[1] that went so far as to declare the use of the Bayes' theorem a heresy.[2] The scientific world responded with outrage to these views, and a number of opinion pieces were published that harshly condemned them.

[1] See: www.maths.lancs.ac.uk/~lucy/publications/position-statement-01-2011.pdf
[2] It should be mentioned here that the appeals court of the United Kingdom believed the use of the Bayesian theorem was suitable to interfere with common sense.

Following the judgment in RvT, 36 forensic experts of ENFSI[3] released an open letter in which they explained their position in regard to the anti-science stance of the appeals court.

Use of Bayesian methods in penal practice

In cases of minor offences or where the risk of repeat offence is improbable, using a Bayesian Network to evaluate the circumstances can assist in determining to what extent house arrest would increase the risk of repeat offence or of committing any other crimes in regard to the given convict. It would benefit the internal order and security of penal institutions if convicts assigned to the same call were selected after a preliminary evaluation of the convicts' behaviour and past, thereby reducing the number and the severity of internal incidents. A study conducted in the State of Utah revealed that future loads of penal institutions can be forecasted by creating suitable Bayesian models (Blattenberger et al., 2010).

Bayes and prevention of crime – subjective probability in criminology

Using a Bayesian Network it is possible to identify areas where criminological observations and the associated probability values can be taken into account. Based on follow-up analyses, using the year of 2006 as basis until 2010, the results showed a declining trend in regard to the number of violent crimes in Memphis, which was more favourable by almost 10% than the average crime rate in the United States (Vlahos, 2012). An excellent example of an interdisciplinary search for solution is the *Blue CRUSH (Criminal Reduction Using Statistical History)* system implemented as part of a cooperative effort between IBM and the city of Memphis. It combines collection and processing of a huge amount of criminal statistical data, and uses the trends to calculate probably crime hot spots (Strickland, 2014). Using a surveillance theory model, input was based on deductions made from information provided by signal transmitters attached to the arms of repeat offenders (Orbán, 2016) and cameras, sound samples captured by acoustic sensors and audio spectrum data suggesting the use of a firearm, which are then employed to identify current hot spots. Prevention of crime can be a factor in city development plans or at the time of renovating city districts. Criminological analyses of the city of Bangkok also indicate potential uses in crime prevention (Boondao, 2008).

Forensic and mathematical approach to Bayesian methods

Scientific reasoning and, in particular, finding proof based on mathematical and probability calculations, uses a language that differs from that which is used and expected in the courtroom (Sallavici, 2014: 188.). Judges are only required to know mathematics, decision theory, Boolean algebra, game theory and probability calculus so as to understand and take into consideration the reasoning of the forensic expert. On the way to the solution – i.e.

[3] European Network of Forensic Institutes.

the use of scientific and forensic evidence in the courtroom – the recommendations in the McClure report are worthy of consideration. The committee judges soft and hard evidence based on scientific support. In regard to the first case it recognizes the importance of scientific validation. In terms of science, the committee considers the use of control groups and the prioritization of methods based on validity (scientific error) and reliability (human error) justified (McClure, 2007: 12.). The 9 recommendations made in regard to the forensic experts include promotion of communication between the disciplines involved and the provision of statistical information usable by judges. From the long list of recommendations made to the judges, I would highlight those relating to further education and the status of judicial scientific advisor (McClure, 2007: 12–16.). These two points are particularly important in terms of the correct interpretation of probabilistic evidence and in order to prevent unwarranted exclusion of evidence that is not understood. According to Evett, forensic reports should satisfy four conditions (balance, logic, transparency and robustness).

Bayesian Networks based on the Bayes' theorem and graph theory offer several sophisticated options to forensic scientists. Taroni and Garbolino summed up these options in four points, each of which is related to the acquisition of a certain skill (Taroni–Garbolino, 2001). The four groups: mentality needed for handling uncertain information, the ability to use these methods, capacity to act rationally in an uncertain environment, and the use of data for model building. Expert systems built on the use of Bayesian Networks are categorized as *Probabilistic Expert Systems* (PES) in the English literature (Dawid et al., 2002). These methods are given a special emphasis when the most probable one needs to be selected out of competing hypotheses, and the choice must be underpinned by scientifically sound reasoning.

The advantages of Bayesian Networks appear most markedly in complex multi-variable areas. Such areas include transferred DNA samples or the mixing of DNA samples with human and animal-derived residual materials (Halverson–Basten, 2005). The above parts examined the investigation of some constant, statically stable forensic problem. Law enforcement requires intervening in the course of actions. In such a case, resolving static methods after the act is not productive. Integrated into the processes and adapting to their pace, Dynamic Bayesian Networks appear to be the most suitable. Inclusion of surveillance theory allows for making and updating decisions in response to momentary changes. An example: when an arrest is to be made and the target person's position is known, the records of their past movements can be used to predict the route they will follow in the future so that the place of arrest may be planned.

Demonstration of Bayesian cases in forensic science

Out of the Bayesian methods, we will use methodologies involving Bayesian Networks and Bayesian statistics to investigate a fictitious crime scenario. (This serves as a simple demonstration of utility.) According to the fictitious scenario, a notebook containing sensitive data has been stolen from the boot of a car left in a parking lot in Veszprém. Based on a description, HJ[4], who has a criminal record, can be accused of committing the crime. His be-

[4] HJ: Initials of the fictitious perpetrator.

haviour is known and his criminal career is characterized mostly by casual theft and casual breaking and entering. His area of movement and the distribution of his locations in time: Tata (50%); Budapest (25%); Székesfehérvár (15%); Veszprém (7,5%); Győr (2,5%).[5] He sells stolen items as soon as possible to fences in major cities within his area of movement. He exhibits law-abiding conduct at the place of his permanent residence and in the period preceding the crime in our example theft, breaking and entering or fencing of stolen items were not detected. His intelligence is below the average, he does not like or use computers.

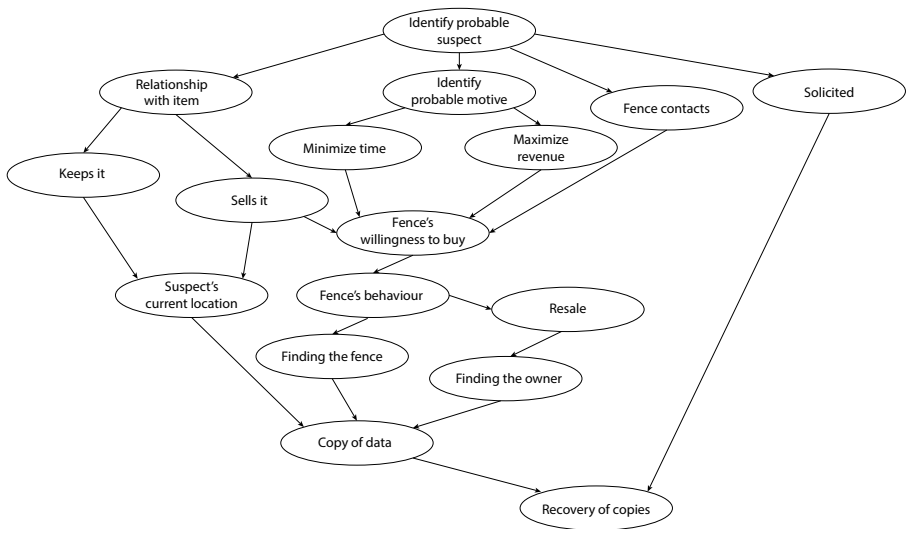

Figure 1
Example of a model using a Bayesian network

Source: Author's own work

The objective can be the arrest of the perpetrator and/or the recovery of the stolen items. In order to prevent the leak of the aforesaid sensitive data, the operation should be concluded as quickly as possible, and any copies of the data that might have been made should be seized (Figure 1).

[5] The presented order of the locations is fictitious, it is not based on forensic statistics, and it is only used to improve our demonstration.

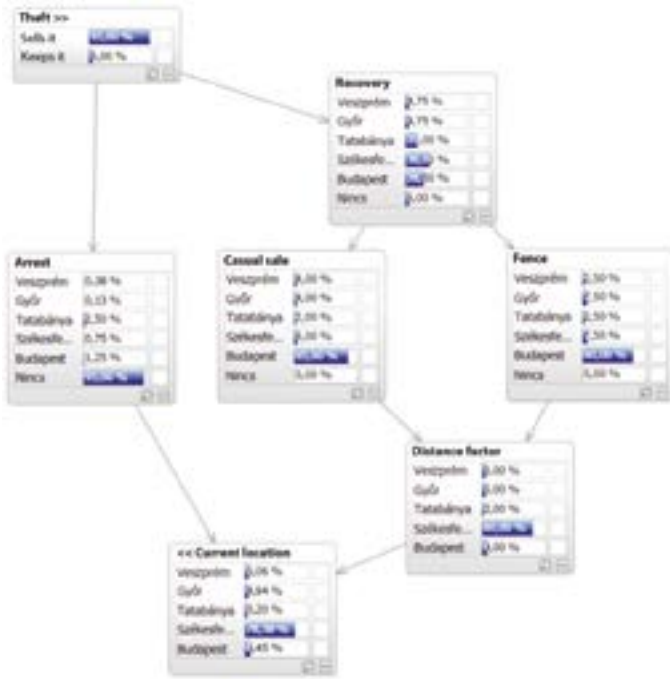

Figure 2

Calculation results of the Bayesian network complete with probability variables

Source: Author's own work

The commander leading the investigation can only focus operational resources on investigating a single location. In order to improve operational efficiency, adding the single events to the nodes of a Bayesian Network we can model their correlations and interactions. Using a table of conditional probability values we can also estimate the strength of their effect (Figure 2). A simulation like this one can reveal the weaknesses of the action plan and the measures that should be prioritized.

Summary

This study has provided a glimpse at the results achieved in the research of Bayesian Networks in forensic science. This promising perspective calls for further research into potential applications and for a more in-depth review of the areas that are already in focus. Further information on forensic modelling, detection of crime, profiling and – in the difficult case of mixed DNA samples – identification and on applications in crime prevention through the evaluation of facts can also be acquired by studying examples of Bayesian Network applications in the literature. After an example of reluctance to use this method in practice, a fictitious case study guides you through a demonstration of utility, which may help professionals working in the field and those interested in the subject understand the concept.

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