Forensic Science International: Synergy 3 (2021) 100162

Contents lists available at ScienceDirect

Forensic Science International: Synergy

journal homepage: www.sciencedirect.com/journal/forensic-science-international-synergy

Forensic intelligence: Data analytics as the bridge between forensic science and investigation

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ARTICLE INFO

Keywords:
Forensic intelligence
Intelligence analyst
Data analytics
Forensic databases

ABSTRACT

Scientists should not play a role in investigations nor should investigators play a role in the scientific analyses. One way to bridge the relationship between the forensic scientist and the police investigator is through an Intelligence Analyst (IA) who is part of the forensic services operation. The IA offers the ability to walk between the role of scientist and law enforcement, receiving data after completion of scientific analyses and translating the information into actionable intelligence. The additional bridging and translating services represent a paradigm shift with increased emphasis on investigative contributions from forensic analysis. Forensic intelligence incorporates forensic data early in an investigation in a holistic case approach that incorporates possible datasets and information that could be relevant to the investigation. We present a brief review of the value added when an IA provides the bridge between the forensic laboratory and police investigators to enhance the use of forensic evidence.

1. Introduction

Can we determine the impact of forensic science on the justice system? Many studies have addressed the question of the value of forensic science and the measurement of those contributions ([1–23]). A fundamental component of that question involves what specific analytical outcomes signify value and how to measure each interpretation of value. To the prosecutor, success follows from the ability of the forensic analysis to support formal criminal charges towards conviction. To the police, forensic science adds value from the support the evidence lends towards confirmation of a link between a suspect and a particular crime scene. To the forensic scientist, the value resides in the independent scientific analyses of evidence samples collected from crimes scenes. To the public, forensic science can provide a reproducible vehicle to provide transparency and trust in our criminal justice system.

Although the criminal justice system includes the roles of police, forensic scientists, and prosecutors, their divergent objectives may conflict. The forensic scientist plays the role of the disinterested third party providing unbiased evaluations of evidence. While the policing organization is interested in that objective analysis, requests for forensic analysis may be limited to a particular perspective and/or limited in scope. Similarly, prosecutors may prioritize the analysis of evidence they believe is necessary for a successful prosecution. For many jurisdictions, the varying objectives lead to an unfiltered submission of potential evidence to the forensic laboratory by the police and a casework prioritization influenced by the prosecution [18]. This process can focus the realized value of forensic science on support for convictions and minimize the value resulting from probative contributions to justice. The systemic use of forensic laboratory testing continues to be dominated by prosecutorial dictates, rather than investigative directives from policing [4,9,24].

Scientists should not play a role in investigations nor should investigators play a role in the scientific analyses. Accredited crime laboratories have policies in place to ensure that forensic analyses are free from undue influence. One way to bridge the relationship between the forensic scientist and the police investigator is through an Intelligence Analyst (IA) who is part of the forensic services operation. The IA provides another service through the ability to walk in between the role of scientist and law enforcement, receiving data after completion of scientific analyses and translating the information into actionable intelligence for investigators. The additional bridging and translating services provided by the IA represent a paradigm shift with increased emphasis on the investigative contributions from forensic analyses. Crime laboratories traditionally issue reports and have little interaction with

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https://doi.org/10.1016/j.fsisyn.2021.100162
Received 28 July 2021; Received in revised form 18 August 2021; Accepted 23 August 2021
Available online 24 August 2021
2589-871X/

investigators for the majority of cases submitted for analysis. Since databases (e.g., Combined DNA Index System (CODIS), Automated Fingerprint Identification System (AFIS), National Integrated Ballistic Information Network (NIBIN)) capture the forensic data for many cases, the same data may contribute to the solution of additional cases. The potential pitfall lies in the lack of information sharing across agencies/jurisdictions. Ribaux et al. suggest "that the forensic science community should participate much more actively in the intelligence debate and initiate an intensive modelling program in order to create a desirable synergy between forensic science, crime analysis, investigation and other fields related to the study of crime" [4]. Researchers continue to express this sentiment, reiterating the same arguments over the past couple decades, including the National Academy of Sciences [7] and more recently a RAND working paper [18]. The National Academy of Sciences recognizes that the advances in forensic science have grown considerably but have outpaced the use of these advances in investigations [7]. The growth in the capabilities of the forensic laboratory have yet to be matched with the up-front use of expanded laboratory abilities to support investigative leads. The dominant use of forensic laboratory resources remains centered in prosecutorial requests to support court cases [18].

The concept of forensic intelligence incorporates forensic data early in an investigation in a holistic case approach that incorporates all possible datasets and information that could be relevant to the investigation. A recent report highlights the underutilization of information obtained from the forensic analysis of various types of evidence [25]. In this Report to Congress, the authors recognize that the traditional reliance on forensic evidence for prosecution is valuable, but that forensic analysis can and should play a key role in the development of investigative leads. Houck extolls the benefits from the early introduction of forensic analysis into investigations and the opportunity for forensic analysis to contribute to intelligence [26]. The criminal justice system then may reallocate limited resources toward more fruitful avenues of inquiry.

We present a brief review of the value added when an IA provides the bridge between the forensic laboratory and police investigators to enhance the use of forensic evidence in active investigations. We begin with commentary on the growth of data analytics in all walks of life from business enterprises to public health solutions during the COVID-19 pandemic, which provides an example of analytics for public good that is relevant in forensic intelligence. We follow that review with commentary on the role of laboratory information management systems (LIMS) to manage data more easily and thus support the IA's ability to readily access forensic documents. The next section looks at forensic intelligence in the literature and serves as an introduction to the implementation of an IA in the Forensic Services Bureau (FSB) of the Miami-Dade Police Department (MDPD) with some examples of the bridge functions of the IA. The corresponding return on investment from the IA follows. Finally, a discussion on future use via expansion of forensic intelligence is offered.

2. Data analytics

The ability to combine data sources across various related entitles is not a new concept. One of the most common ways people interact with systems that combine data from multiple sources is in brand loyalty programs. Many brand loyalty programs create visibility for a customer across many different areas of an organization; they typically combine dynamic transaction information to static demographic information, and at times combine with third party market research information to attempt to give a 360-degree view of a customer, their behaviors, and their needs/wants. Another outstanding example of this is innovations in supply chains, which can combine supply levels in warehouses, with shipping manifests from procurement, to forecasted demand from sales representatives which allow analysts to view the full supply chain and react to mitigate problems in real time. There are countless other use cases where breaking down data silos can enhance decision-making and insights in the enterprise to drive down costs or raise revenues.

But what about in the public domain? Can this same concept be used for public good? The simple answer is yes. One of the best examples of this can be found in the response from the data science and analytics community during the SARS-CoV-2 (COVID-19) pandemic. Large research universities such as Johns Hopkins were able to reconcile information in infection rates and hospitalizations to create a global database on how the pandemic was evolving. This allowed decision makers to understand at a macro level the dynamic situations on the ground and allowed data scientists and analysts in localities to track national and international models of the spread of COVID-19. At a more micro level the nationally recognized response to the pandemic has been facilitated by data sharing across jurisdictions. The Joint Interagency Task Force (JIATF), the entity responsible for West Virginia's COVID-19 response, was built using a team of teams approach. This collaborative combines resources for all state agencies and private organizations, including Department of Health and Human Resources, West Virginia National Guard, West Virginia Hospital Association (WVHA), Public K-12 Education, Higher Education, Long Term-Care Facilities, among many others. The ability to share information in the JIATF from each of these entities has allowed leadership to move on projects such as setting up supply backstops for personal protective equipment (PPE) by forecasting the necessary equipment for each entity in the JIATF at a local level. This was made possible by data collection from each hospital and long-term care facility in the state facilitated by the WVHA, data on the positive test rate by local health departments in each county, as well as forecasting software and methods written by universities within the state. The combination of the required data for forecasting PPE, has led to the ability to develop vaccine distribution technology specifically to increase the accessibility and visibility into populations who need and want the COVID-19 vaccine. These cases are a prime example of how combining different data sources across different entities can help a private enterprise succeed as well as enable public entities to benefit their communities.

Law enforcement uses intelligence information to develop strategies that can disrupt or deter patterns of criminal behavior. To that end, law enforcement agencies are increasingly embracing new technology such as license plate readers, drones, red light and other digital cameras, digital forensics, and gunshot acoustic technology. So much information is now available that Real Time Crime Centers (RTCC) have been established at law enforcement agencies all over the United States to provide real time assistance to law enforcement officers. Across the nation, Crime Gun Intelligence Centers (CGIC) have also been established, many in conjunction with the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), to provide intelligence related to gun crimes.

The CGICs use forensic intelligence, law enforcement intelligence plus forensic data obtained from different cases, to link crime scenes, materials, and persons of interest. However, the concept of forensic intelligence has been slow to catch on in policing; intelligence analysts are not routinely looking for data trends within forensic data fields. Legrand and Vogel refer to forensic intelligence as the "structured assimilation of forensic data (i.e. crime scene evidence such as DNA, fingerprints, ballistics, and trace evidence) within a cross-referenced and indexed dataset" [27]. As an IA connects details from various data sources, patterns emerge to enhance strategic, operational, and tactical plans.

Furthermore, predictive policing, which utilizes historic crime data to inform current and future decision making on crime prevention, provides an example of how data analytics and machine learning can be used in crime prevention [28–30]. The ability to develop new techniques to create interventions provides insight into tools law enforcement can make decisions on in the future [31–33]. These methods and concepts may be the result of researcher-practitioner partnerships, which are a foundation of translational criminology. In these environments, law enforcement partners with researchers to make a practical impact in policing. Nichols et al. review a variety of researcher-practitioner partnerships and outline the importance of these partnerships for law enforcement, which use evidence-based approaches, such as analytics, to consider the importance and evaluation of policies [34]. These partnerships lay the foundation for impactful policing and hot spot detection. There are many benefits to law enforcement agencies through these partnerships, specifically the ability of researchers to base results in scientific theory using analytics and outside objectivity [35]. This concept diverges slightly as translational criminology focuses on preventive measures, while the IA, is focused on detecting and utilizing trends on open cases, and connecting the various data sources to provide a complete picture of related events. The ability for the IA to utilize various data sources to target open investigations is a key differentiator between the two rules and places distinct value on the role of the IA and the ability to add real-time context to decision making.

What can forensic intelligence resulting from mining big data associated with forensic science examinations offer investigations? The role of forensic evidence when used to develop investigative leads will result in faster turnaround times and lower investigative costs [18]. For example, the use of NIBIN, a computer imaging system that allows the firearm and toolmarks examiner to link cases with same-gun evidence, provides one bridge to investigation [7].

2.1. LIMS

Recent analysis of the value of forensic evidence points to two factors that significantly contribute to clearance rates [18]. One significant factor is associated with fee-based services provided by the laboratory. Traditionally, law enforcement agencies submit evidence for analysis that is unnecessary for the investigation of the case. When a price is associated with the analysis of forensic evidence, however, the number of items submitted to the crime laboratory is often limited to those items believed to be critical to the investigation. This attention to sample selection prior to submission results in faster turnaround times and increased case throughput. The other significant factor is whether the laboratory has a LIMS. The key to better probative use of the forensic science data is to find the means for the forensic laboratory to share viable leads from this data with investigators without giving up the objective independence of the scientific analysis [37].

A Bureau of Justice Assistance report highlights some of the possibilities that appear when the casework of forensic laboratories are supported by a LIMS. If the policies and procedures of the laboratory and the associated policing agency (or agencies) include linkages between the LIMS and the underlying police reports, then the potential search capabilities are enhanced. Searches across evidence, cases, suspects, geography, and/or associates offer greater intelligence capabilities and bridges the gap between disparate agencies [37]. Alternatively, this information could also be accessed from other databases containing law enforcement information. Ultimately, a LIMS or other information system can assist, but it is the synthesis of information from a plethora of databases that produces the investigative lead.

As data collections continue to get bigger, coordinated computing power via a LIMS can successfully turn big data into leads [36]. This is where forensic intelligence may play a big role in support of the justice system through the ability to connect various databases with other sources of information in the investigative process and link data across disciplines to generate connections to current and former crimes [37]. For example, a DNA profile from one case may be linked to other cases via a DNA database; that same individual may also be identified on additional cases via fingerprints. This information can be linked using a LIMS and analyzed to provide potential actionable intelligence.

Anderson et al. collected data on several test laboratories and connected forensic data collection and examination to various crimes [18]. When it came to homicide, the average test laboratory collected forensic data for over 90% of cases. However, the average forensic laboratory in the study was tasked to analyze that evidence in only 63.63% of the cases. For forcible rape, the average collected and average analyzed data occurred in 78% and 38% of cases, respectfully. For aggravated assault, the collection was 48.5% and analysis a mere 6.75%. For non-violent crime, analysis of forensic evidence occurred in only 2% of robbery cases and less than 1% of the burglary cases.

Convenient access to large databases enhances the ability of an IA to take a cross-disciplinary approach to the linkage between forensic intelligence and police intelligence. The laboratory has access to many key potential cross-disciplinary connections to assist in intelligence gathering. The LIMS includes detail across forensic disciplines and the laboratory has access to key databases (e.g., NIBIN, NDIS, AFIS) that when connected offer forensic intelligence towards investigative leads [37]. Such cross-disciplinary analysis has been a traditional use of intelligence by other investigative bodies such as the FBI and the military and has proven effective [7].

3. Forensic intelligence

While forensic examiners in crime laboratories nationwide are often the first to identify crime trends through searches of forensic databases that can, for example, identify a subject via a common DNA profile or fingerprint or link cases associated with same gun evidence, a more commonplace method for the identification of crime trends is through the use of intelligence-led policing. Intelligence-led policing commonly fuses analyzed information to inform police resources and strategies, relying on the concept of recidivism and the observation that a small number of offenders commit the majority of criminal acts [38].

"Pre-arrest suspect identification seems a stage at which the objectivity of forensic evidence and its lack of correlation with other sources of information about a suspect would recommend its use" [18]. However, the disjointed objectives within the justice system often limit the use of forensic science to confirmatory purposes, if used at all. Strom & Hickman emphasize the capabilities of forensic intelligence to provide those early leads. This is especially true of some of the identity forms of evidence such as fingerprint identification and DNA analysis, which can each provide early leads in an investigation [24]. While NIBIN does not provide a direct lead to a person in the same way that a DNA profile or fingerprint can, the intelligence information is valuable to an investigation.

Yet, studies indicate that the great potential from forensic intelligence is not accessed [18,24]. The abundance of gun violence is driving the need for forensic evidence to inform investigations not only at a national level but at state and local levels as well. The information available from myriad sources needs to be analyzed and retained in a searchable format. As each investigative entity moves from case to case, information is lost, contained in single case files, creating silos of information that could have potentially solved another crime. The fact that forensic data is not utilized to its capacity is already known. An example of the underutilization of such data was the opioid crisis, forcing a collaboration between medical examiners, toxicologists, crime laboratories, law enforcement, and other first responders in jurisdictions nationwide, to help identify, understand and address the opioid problem. This collaborative effort helped identify information such as hotspots in communities, similarities in drug types, and sources of the illicit drugs. If the information resulting from forensic analyses had been part of the intelligence information from the beginning, trends could have been identified sooner, perhaps saving lives. While some jurisdictions are now starting to recognize the importance of using forensic data, the applications to date have been limited.

Through the identification of cases linked in NIBIN, crime laboratories can assist investigators with the identification of individuals involved in specific crime areas by prioritizing the forensic analyses as necessary, providing forensic information to produce actionable intelligence and directing limited laboratory and investigative resources where they are most needed. Ultimately, crime laboratories are the messengers of underutilized forensic information contained in highly technical reports that may be misunderstood by laboratory stakeholders.

Bridging the gap requires a creative eye towards the problem. Intelligence analysts already mine commonly used data sets such as arrest warrants, offense incident reports, and vehicle information. If all NIBIN links could be assigned to an intelligence analyst, including those associated with lesser priority crimes, intelligence could potentially identify associated individuals earlier in the gun cycle, disrupting or deterring gun crime.

Intelligence takes data from various sources, makes observations and connections, and turns analysis into more than the sum of its parts [39]. Information sharing across jurisdictions is limited both between law enforcement agencies and between crime laboratories, yet the sharing of forensic data sets is critical to gun crime investigations. Ultimately, if timely data resulting from crime laboratory systems and processes could be incorporated by intelligence analysts into the investigative process for all cases, forensic results could inform investigations and all entities could focus valuable resources where they are needed.

4. Miami-Dade County

The MDPD established a RTCC in 2015. ShotSpotter, a gun acoustic technology system, was implemented in several known high gun crime areas in Miami-Dade County under the purview of the MDPD in 2017; these areas were expanded in 2019. Acoustic gunshot detection systems use sound sensors to locate gunshots in a community as well as improve response times to gun violence [40]. Currently, casings associated with ShotSpotter detection are submitted to the MDPD FSB and are prioritized, processed, and entered in NIBIN within 24 h after submission to the laboratory. If a candidate match is identified in NIBIN, this link will be reviewed by a trained firearm examiner. After this review of the images in NIBIN, an automated preliminary notification of this NIBIN link is sent to the lead investigator(s). The notification provides a list of associated case numbers by gun evidence (e.g., 9 mm casing, 0.40 casing) but does not provide any associated case details.

All firearm related evidence is analyzed in the Forensic Identification Section (FIS) of the FSB. Every auto-loading firearm confiscated in Miami-Dade County is test fired and searched in NIBIN against all the digital images in the NIBIN system. When evidence casings are submitted to the FSB, they are triaged by a firearm and toolmark examiner for NIBIN entry to determine how many firearms may have contributed to a submitted group of casings. For example, if ten 9 mm casings are submitted in a particular case, the FIS will determine if all ten casings were potentially fired by one firearm or by multiple firearms. One representative casing from each potential group is selected for NIBIN entry to represent each firearm present. Confirmation of the number of firearms present occurs when the evidence casings are physically compared to test fires from a particular firearm on a stereomicroscope.

When the MDPD expanded its use of ShotSpotter in 2019, the FSB was able to acquire one IA to assist with NIBIN Crime Gun Event (CGE) Reports.). This is the first time that an IA has ever been embedded in the MDPD FSB. The initial vision was for the IA to analyze data associated with cases with higher priority that were linked to other cases in NIBIN. In direct contrast to quantitative data typically collected by law enforcement such as number of arrests and number of ShotSpotter cases with evidence collected, the IA connects the dots across cases linked in NIBIN, mining qualitative information and translating the information into actionable intelligence. The IA uses information gleaned from sources including, but not limited to, arrest warrants, offense incident reports, social media accounts, cell phone data, background checks, vehicle information, serial numbers and other unique identifiers, victim information, known associates, and gang information. The IA is also tasked with linking other forensic-related case information such as known links resulting from searches of DNA and fingerprint databases to the investigative information arising from the NIBIN link. All the information gleaned from this research is used to populate the CGE reports that are subsequently sent to the lead detective. In essence, the IA is translating the underutilized forensic information contained in highly technical reports into a format that can be understood by our stakeholders. This process illustrates a version of a forensic intelligence model that was also supported by Houck [26].

On average, the current IA was able to produce approximately two to three CGE reports associated with major crimes per week over the last year. An average report included the research of at least 20–25 cases. Each report is dependent on the number of cases linked together and varies in complexity. For example, if three cases are associated with one 9 mm firearm, the information analysis may take longer than if only two cases are linked.

While the FSB issues reports to investigators for all NIBIN links, including those associated with lesser priority crimes, these links to lesser crimes were not routinely assigned to the IA for data mining/intelligence. However, the IA is extremely adept at piecing information together for law enforcement. As a result, the requests for CGE reports have expanded to other types of cases involving firearms such as drive-by shootings or non-contact shootings. Over the last year, the demand for the CGE report for all types of cases has increased exponentially. There is no doubt that investigators have begun to understand the value of this type of data analysis. The requests for CGE reports are now submitted from different entities including, but not limited to, the United States Attorney's Office, MDPD investigative bureaus and district stations, and municipal agencies. In fact, the number of requests for CGE reports from January to March 2021 increased by approximately 250% over the same three-month period in 2020.

5. Miami-Dade cases

Consider an example of the work done by the IA to extract forensic data and link it to the police investigation. This example involved the use of ShotSpotter and NIBIN.

This case is relatively straightforward. It began with the police responding to a ShotSpotter indication of a shooting on December 30. The police discovered three gunshot victims with one victim deceased. The police recovered eleven 9 mm casings and four 0.40 S&W casings. There were no witnesses identified beyond the surviving victims. The forensic laboratory received the casings from the December 30 homicide, examined them, and made the NIBIN entry. Meanwhile, the IA met with the investigator and reviewed the case file for details. There were few details and no immediate leads beyond the casings and the social media footprint of two of the victims.

The homicide on December 30 left one dead and two wounded, but provided little detail to the police investigator. The lack of a weapon or possible suspect led the investigator to seek the assistance of the IA and the affiliated forensic data.

The IA acts as the intermediary between the forensic laboratory and the police investigator with access to police and laboratory databases as well as publicly available data sources. The ballistics analysis in the laboratory suggested a link between the 9 mm casings with an aggravated assault that occurred ten days before the December 30 homicide. The December 20 aggravated assault involved shots fired at three victims. Police recovered three different types of casings: eight 9 mm, eight 0.40 S&W, and three 0.25 ACP.

NIBIN provided a link between the 9 mm casings at the December 20 aggravated assault and the December 30 homicide. The IA used that connection and added details regarding the criminal past of suspects, witnesses, and victims on both cases to uncover additional connections. Open source intelligence along with social media profiles of all parties involved were also analyzed.

The number of social media profiles that were of interest expanded as additional associates tagged themselves with known social media accounts of interest. Comments, pictures and even videos uploaded on these accounts assisted in drawing a picture of the events that led to the homicide on December 30. Publicly shared comments and videos on these social media accounts showed that the victims were starting their own drug business and infringing on another territory. In January, shortly into the IA's review of the case, a weapon was recovered from the follow up investigation of another homicide case that had occurred on December 11. The test fires from the recovered weapon provided a link to the 9 mm casings found at both the homicide from December 30 and the aggravated assault on December 20.

In this earlier homicide on December 11, investigators had arrested suspects, gathered 9 mm casings, but lacked a weapon. While the 9 mm casings did not link to the casings recovered from the other two shootings, the search of one suspect's apartment on January 3 yielded the firearm with a NIBIN link to the homicide from December 30 and the aggravated assault from December 20. This physical evidence, combined with the story culled from social media, permitted the IA to provide the investigator with the case details to pursue. Connecting the forensic evidence from NIBIN to the initial investigation began to narrow the investigation. The review of social media proved to be a critical element in connecting the three cases. As the story unfolded, the IA suggested that the data gathered from law enforcement, forensic, and social media sources indicated that a new gang of drug dealers infringed upon the territory of other drug dealers and the crimes ensued.

This represents a relatively simple case; the IA was able to gather the links and present the information to the investigator within approximately 24 h. Other cases can be much more complex and require the IA to link data from sources such as ShotSpotter, NIBIN, incident reports, arrest records, and social media searches. These sources can provide enough information for the investigator to overcome the limitations of finite physical evidence, inconsistent witness testimony, and uncooperative victims. The IA is able to master data extraction such as addresses, names, gang membership, and other available data from multiple sources to provide actionable intelligence, while the crime laboratory is able to maintain scientific objectivity.

6. Return on investment

Does an investment in an IA make fiscal sense? Economists often calculate a measure, return on investment (ROI), as a means to weigh the costs versus the benefits in any endeavor. With public sector expenditures, such measures permit easier comparison between competing demands for public funding. The measure itself is relatively simple. ROI is the ratio of the net benefits (total social benefits minus total costs) divided by the total costs. Thus, a ROI of 10% indicates that for each one dollar of public spending, a return of $1.10 emerged (($1.10 - $1.00)/ $1.00).

Peterson et al. when attempting to answer the question on the value of forensic evidence, note that the existence of forensic evidence was associated with higher conviction rates [9]. They also note the lack of empirical evidence to support the gains to the justice system from the investment into forensic analysis [9]. They call for further collection of cost data to be able to assess the value and associated ROI from probative use of forensic evidence. Since that call, several sources of cost and benefit data have emerged that will permit the ROI determination [15, 17,22,23,41-44].

The additional costs from hiring an IA are largely comprised of personnel expenditures on salary and benefits with low additional costs from hardware and software support, as well as the training associated with these tools. These additional costs are small in comparison to the measurable benefits provided by the IA. Those benefits include tangible and intangible benefits from several sources. First, the IA offers a bridge between the forensic laboratory and the investigator that provides a timesaving for the investigative officer, freeing up resources towards other crime investigation or prevention. Potential investigative resource savings are greatest with violent crime. For example, a ten percent to fifty percent cost reduction in homicide investigations provide savings that range from roughly $18,800 to over $94,000, while similar percentage savings from rape investigations range from $2,866 to $14,332 [9].

Return to the Miami-Dade experience, highlighted in the prior sections. Note that the State of Florida has traditionally been proactive in its use of forensic science to aid in investigations. The state was one of the pioneers as an early adopter in pilot-testing CODIS prior to its widespread implementation in the United States in 1990. While CODIS was initially utilized for sexual battery cases, its application within Florida expanded almost as quickly as legislation could be written. In the early years of CODIS, qualifying felony offenses were incrementally added for collection of DNA samples. In 2000, burglary was added as a conviction offense in Florida; data analyses conducted by the Florida Department of Law Enforcement determined that 52% of the offenders in Florida's DNA database who were convicted of property crimes had a prior violent arrest. Similarly, 59% of violent convicted offenders in the State of Florida's DNA database had a prior burglary arrest [45]. The addition of burglary was based on the idea of preventing future violent crime: if there was a way to identify the offenders sooner via evidence left behind at a crime scene, the perpetrator could be removed from the streets before their crimes escalated.

The Miami-Dade experience has shown that the addition of the IA has resulted in the ability to populate two to three CGE reports per week. To illustrate the ROI from the IA, suppose that the cost of the IA is $100,000 annually (salary, benefits, and supporting expenses). That cost translates into roughly $400 per workday. With two to three CGE reports per week, the cost of the IA for the average case is about $800. The IA's work in the example provided support to two homicides and one aggravated assault. If the benefit was as low as a 10% savings for each linked case, then the ROI would be 4,753%.[1] If the investigation savings were as great as 50%, then the ROI from the IA would exceed 24,000%.

That merely represents the savings from investigation. Additional benefits may be attributed to the increase in DNA profiles from arrestees. Anker and co-authors estimate the impact of an addition to the DNA database from an arrestee profile and show that a 1% increase in the likelihood of apprehension reduces crime by 2.7%. This impact is even more pronounced when an arrestee is young (23 and under) [46]. Heaton measured the societal benefit from the avoidance of a single crime [42]. Estimates of the average benefits range from a low of $2,750 for larceny to a high that exceeds $11 million for homicide.

These potential benefits are enormous. However, determining the ROI from the employment of intelligence analysts requires a more detailed study that captures the full impact pre- and post-employment. That requires examination of the experience with crime rates, police and laboratory case throughput, and agency expenditures, while controlling for external influences. The illustration above suggests the societal gains are dramatic. Responsible allocation of public funds is dependent upon such event studies to allocate tax dollars among competing uses.

7. Moving forward

Expanding the role of forensic science from investigation through the entire justice system process has the opportunity improve the efficiencies for police, forensic scientists, and prosecutors in the application of justice [24].

In machine-learning, the "curse of dimensionality" says that the more information is used to predict something, the further it gets from any other observed case in the data. As data from forensic LIMS and other law enforcement databases is combined with a more holistic picture of a crime, other crimes can be constructed. If these data sources are combined with open-source public data, then layered with social media intel, the curse of dimensionality has become applicable in forensic

[1] A homicide investigation has an average cost (in 2020 dollars) of $188,025 and an aggravated assault has an average cost of $12,189. For two homicides and one aggravated assault with the IA cost of $800, then the ROI is calculated as ($18,803+$1219+$18,803-$800)/$800.

science as the boundless number of combinations of data sources is mined for connections and the IA must be careful not to get lost down the rabbit hole. This concern brings to light some fundamental questions. What is the importance of the data sources? How will the analyst be able to identify the right data sources for the right investigation? Are there best practices for efficiency? Should the value of a data source be assigned based on the ability to connect across different interests of an investigation or the value it brings to ending an investigation? This is just the beginning of numerous questions we can dive into including data privacy, ownership, and governance. While not as publicly intriguing as data privacy and ownership, data governance in these databases must be a primary focus as the public good that is done with this information is critical and changing the data itself can lead to major issues such as information loss in investigations, as well as retraining of stakeholders.

Successfully using data analytics has shown tremendous returns in other arenas. The profitability of private enterprises such as Amazon, Alphabet, and Facebook is highlighted in the financial press. The key role of the use of big data by the public sector in combating the COVID-19 pandemic is evidenced by those countries that have managed to efficiently distribute personal protective equipment and vaccines. The justice system possesses large databases in policing, forensic laboratories, and the court system. Successful mastery of these sources, along with publicly available data outlets, offers the promise of significant returns to the public. The actual gains from training intelligence analysts to assimilate forensic data must be measured and leveraged to efficiently allocate public funds, enhance the safety of communities, and maintain public trust.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The project described was supported by the National Institute of General Medical Sciences, 2U54GM104942-02. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

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