forensic sciences

Article

Intelligence and the Value of Forensic Science

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Abstract: Recent research has seen a rapid expansion in the reference to front-end forensics as an indication of the untapped value of forensic science. While some of these contributions have centered on development of forensic intelligence from a single area of investigation, others call for a more fundamental change in the relationship between crime laboratories and policing, particularly relating early laboratory analysis with big datasets to provide leads to investigators. We highlight several recently implemented tactical strategies of crime laboratories that contribute to the body of forensic intelligence. Beyond the scientific gains from these tactical applications, the corresponding details on associated efficiencies, costs, time savings, and quality improvements offer insights towards patterns of success for the community of crime laboratories. Further details expand an interpretation of what constitutes success with an eye on the contributions of the crime laboratory towards public health, safety, and protection of the innocent in addition to societal gains from conviction of the guilty. The economic interpretation of the value provided by the forensic laboratory assists in the cost–benefit review of strategic and tactical decisions and supports the justification for laboratory public funding with measures of the return on investment from public support of the forensic laboratory. Examples of the cost savings from crimes avoided include the returns from testing the backlog of unsubmitted sexual assault kits with USD 81 of costs avoided for each USD 1 spent to high-efficiency laboratories achieving gains of USD 646 for each UD 1 spent on de novo case submissions.

Keywords: forensic intelligence; cost–benefit; return on investment; front-end forensics

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Citation: Speaker, P.J. Intelligence and the Value of Forensic Science. *Forensic Sci.* **2024**, *4*, 184–200. https://doi.org/10.3390/forensicsci4010011

Academic Editor: Pawel Waszkiewicz

Received: 23 January 2024
Revised: 5 February 2024
Accepted: 6 March 2024
Published: 18 March 2024

1. Introduction

Defining, measuring, and determining the value of forensic science continues to be an issue of great interest for forensic laboratories. The contribution that forensic laboratories provide within the justice system has different meanings across the realm of those affected by the scientific analysis provided by laboratories. The police and investigators may desire greater front-end analysis by the forensic laboratory towards leads, while prosecutors' requests may emphasize confirmatory analysis to support claims against a known suspect. This tug between front-end and back-end analysis can easily tax the limited resources of the laboratory. Other stakeholders, including victims, defense attorneys, the general public, the accused (both innocent and guilty), legislators, and other funding bodies, each have interests in the allocation of resources, but with a plethora of motives. Given the economic problem of limited resources to meet the seemingly unlimited demands upon the laboratory, choices must be made to ration the resources of the laboratory. It is imperative that the crime laboratory be able to measure and compare the values returned from alternative uses of the limited resources if they are to make informed choices.

Addressing the issue of the value of forensic science across all stakeholders remains an essential ingredient in the allocation of public funds to crime laboratories [1–3]. An examination of both front-end forensics and back-end confirmatory forensic sciences contributions offers an indication of value. While much has been achieved in measuring the return on investment towards convictions and exonerations, little attention has been paid towards measurement of the value of front-end forensics.

However, recent developments in intelligence operations provide indications of the return on investment that may be expected from enhanced front-end investments. With the implementation of enhanced intelligence systems, the potential value of forensic sciences in the administration of justice may be realized. An appreciation of the full extent of the contributions towards enhanced intelligence requires the continual collection and analysis of data from these enhancements. The competition for public funds is fierce. Crime laboratories compete with all other uses of public funds, including other uses within the justice system. The implementation of new processes for greater use of front-end forensics must be accompanied by rigorous tracking of inputs and outputs to determine the performance against intended outcomes. That includes the measurement of metrics, such as return on investment (ROI), which permit funding bodies to efficiently allocate limited public funds.

The estimation of the societal benefits from investment in forensic sciences are developed from the avoidance of harms. The statistical process takes relative frequencies from experience as a proxy for probabilities of harms and multiplies those relative frequencies by the average costs (direct and indirect) from the harms to provide the benefit from costs avoided.

The sections that follow trace the heightened interest in the recent literature in the development of forensic intelligence to both investigative leads and provide enhanced safety and health. The experience of several crime laboratories offer examples of how other laboratories might enhance the use and resulting value of data already in their possession or data that is easily obtained. The observation of current intelligence efforts suggests data monitoring that will reveal the value that the forensic laboratory provides.

2. Materials and Methods

The data used in this project comes from Project FORESIGHT [4]. Project FORESIGHT was created as a means for laboratories to self-examine their use of limited resources against the standards of the community of forensic laboratories. FORESIGHT connects the mission and strategic objectives of the laboratory to the underlying performance metrics, highlighting activities that indicate success or room for improvement. The intent of Project FORESIGHT is to illuminate successful strategies and/or change unsuccessful efforts. Project FORESIGHT data tables provide the efficient cost expected for the level of casework activity of a laboratory [5–14].

Measures of benefits derived from various forensic analyses follow from several published studies highlighted below. The methods demonstrated for the cost–benefit comparisons and return on investment (ROI) calculations borrow from several event studies. Since benefits from forensic intelligence generally are detailed from costs avoided, expected costs associated with specific crime studies are used. To these expected costs, relative frequencies of analytical outcomes are used as a proxy for probabilities.

Demonstrations of this estimation technique may be found elsewhere (e.g., the testing of sexual assault kits [15–17]). In these ROI estimations, the authors take a conservative perspective using relative frequencies from the existing literature to estimate the value of testing previously unsubmitted sexual assault kits (SAK), de novo SAKs, and rapid DNA systems. This methodology is extended in the present manuscript for estimation of benefits from all crimes and corresponding forensic analyses.

3. Results

3.1. Recent Literature on Forensic Intelligence

Several recent plans for forensic intelligence implementation have been offered (e.g., [18–24]). Houck [21] argues that the value of forensic science can be realized once it becomes a part of a strategic integration with investigation. The integration of preliminary forensic science interpretations will lead to greater efficiencies across the justice system and reduced costs to society. Baechler et al. [18] propose a holistic model of forensic science reasoning by connecting forensic evidence, intelligence, investigation, and evaluation.

Delgado et al. [19] highlight the implementation of a forensic intelligence process in the Forensic Services Bureau of the Miami-Dade Police Department (MDPD) through the creation of an intelligence analyst (IA) position as a bridge between the forensic laboratory and investigators. These recent additions to the understanding of forensic intelligence follow from a strong foundation in the crime-related intelligence literature (e.g., [25–33]).

Similarly to the aforementioned articles, some considerations of forensic intelligence propose systems for implementation, while other considerations are specific to areas of investigation. Earlier studies tended to be concentrated in a few areas of investigation, including DNA [34–38], drugs-controlled substances [39–41], or firearms and ballistics [42–44].

Subsequently to these publications, there have been several manuscripts that highlight the key role of intelligence involving the crime laboratory [45–57]. While these manuscripts address the role of intelligence in general, other contributions to the literature address the role of intelligence in specific areas of investigation including crime scene investigation [58,59], DNA [60–78], digital evidence [79–88], document examination [89–91], drugs-controlled substances [38,40,66,92–106], explosives [107–110], fingerprint identification [68,111,112], fire analysis [113], firearms and ballistics [43,44,114–117], gunshot residue [118,119], marks and impressions [120–122], toxicology [123,124], and trace evidence [45,125].

The key to realizing the value of forensic science requires developing a systematic way to incorporate forensic science into the intelligence process [126]. Several alternatives have been suggested regarding the incorporation of forensic information into intelligence (e.g., [18,20,22,25,28,30–32,54,126–132]). Recent projects highlight the implementation of laboratory success with the conversion of forensic analysis into forensic intelligence, and some of these are highlighted below [6,26,30,31,101]. Each example represents the tactical implementation of an intelligence strategy.

For each strategy, the unanswered question involves the measurement of the cost–benefit relationship from the implementation of a forensic intelligence strategy. Real-time dashboards contribute to the enhanced value from forensic laboratory analysis. With real-time database extraction, the laboratory may contribute with some sentinel value forewarning policing agencies and public health, connections between individual crimes, and other expanded intelligence.

3.2. The Economic Problem and the Crime Laboratory

With limited resources and a growing demand for analyses, crime laboratories seek greater efficiencies. Project FORESIGHT offers a means for forensic laboratories to benchmark their laboratory performance against the standard performance exhibited by other laboratories [4]. Laboratories have access to a large amount of data, including internal laboratory information management systems (LIMS) and external local and national databases (e.g., CODIS, IAFIS, NIBIN). Laboratories may also have access to databases for personnel and financial record keeping.

FORESIGHT data submissions require the extraction of data from several potential sources. The annual FORESIGHT reporting takes casework data across areas of investigation from the laboratory's LIMS (commercial package or home-grown system) and combines those data with personnel allocation and financial performance, each which may come from a different database. While a laboratory's participation in Project FORESIGHT is voluntary and free, the cost in time when the disparate data sources lack coordination, may discourage participation in the project.

The American Society of Crime Laboratory Directors (ASCLD) addressed this difficulty with a grant proposal, FORESIGHT 20/20 [11]. The ASCLD project proposal called for the creation of software that would link the data in the major commercial LIMS providers to the FORESIGHT submission tool, LabRAT, converting the laboratories casework detail to the uniform definitions in FORESIGHT. Additional details in the grant proposal included extraction for annual reporting of U.S. Department of Justice requirements. FORESIGHT 20/20 was successfully funded through the Laura and John Arnold Foundation.

The project manager for FORESIGHT 20/20 engaged 2nd Logic LLC to create the interface between the various LIMS providers and the automated outputs of completed LabRAT forms for FORESIGHT submission and various U.S. Department of Justice reporting forms. 2nd Logic LLC initiated the development of additional products to enhance the informational value of the existing databases. While Project FORESIGHT collected annual data from the laboratories, the FORESIGHT metric definitions could be applied to real-time data for time periods other than a year. Through the FORESIGHT 20/20 project, 2nd Logic LLC reproduced the FORESIGHT metric definitions for application over whatever period the laboratory desired, such as monthly or quarterly performance. The real-time metrics connected the LIMS to a desktop dashboard so that laboratory managers could monitor laboratory performance on a concurrent basis, illuminating trends in productivity, efficiency, turnaround times, and backlog.

The dashboard enhancement did not require the acquisition of additional information. Rather, the real-time access enabled an expanded use of data continually added to the LIMS. Much of the recent literature highlights the efforts by crime laboratories to enhance the use of available data sources to improve outcomes of the justice system, thereby increasing the value of that forensic analysis. That increased value is observed via sentinel impacts and other contributions to forensic intelligence. Eventually machine learning and other artificial intelligence will be able to build upon human intelligence in the use of big data sources.

3.3. Applications of Front-End Forensics

The enhancement of real-time monitoring of activity has enhanced the performance of many crime laboratories. Consider a few of the innovations that have increased the contributions to forensic intelligence.

3.3.1. Arkansas

The Arkansas State Crime Laboratory enacted a program to make real-time data a greater part of daily workflow and resource allocation as an outcome of the FORESIGHT 20/20 grant program. The laboratory monitors several FORESIGHT metrics on a real-time basis with an emphasis on productivity, turnaround times, and backlogs. The customized dashboards created by 2nd Logic enable the Arkansas crime laboratory to monitor progress from the adoption of Lean Six Sigma practices. Their Lean Six Sigma program was adopted initially to balance the workload between antemortem toxicology cases and the post-mortem toxicology cases. The successful rebalancing in toxicology led to the adoption of similar practices throughout the laboratory. The combination of FORESIGHT metrics, benchmarked against participating laboratories and over time for the Arkansas laboratory provided evidence of laboratory resource demands and tracked strategic initiatives for success.

The dashboard enabled the laboratory to become nimbler in its allocation of resources and resulted in increased productivity, a shortening of turnaround times, and a reduction in backlog. The Lean Six Sigma program led to greater cross-training within the laboratory and the dashboard offered immediate indicators of success. The cross-training enabled the laboratory to shift personnel to meet some of the most critical issues of the last decade from the testing of previously untested sexual assault kits to the rise in fentanyl-related deaths to resource allocation during the pandemic. Extracting real-time data shared at regular whiteboard meetings on progress enabled the laboratory to meet legislative mandates on turnaround time and successfully attack a 5000-case backlog. Arkansas highlights one example of optimizing the use of large data sets already in possession of the laboratory to simplify access and coordinate a tactical strategy for greater efficiency in the allocation of resources.

3.3.2. Houston Forensic Science Center

The Houston Forensic Science Center (HSFC), using in-house programing, created a management dashboard as a linkage between the Center's LIMS and the desktop computers in each section of the HSFC. The dashboard provides real-time updates on the workings in the laboratory, including many of the key performance indicators benchmarked in Project FORESIGHT.

HSFC's attention to real-time data has been highlighted in their drugs-controlled substances area of investigation [39]. HSFC attention to local trends offered benefit to public health and public safety as the laboratory noted the heavy regional increase in phencyclidine (PCP) in impaired driving cases. The HSFC experience highlights that "value" in forensic science may be found beyond convictions. Generally, a measure of the cost–benefit relationship of any public funding includes a full range of the direct and indirect benefits that are generated to society from the allocation of limited public funds. Too often, the measure of the returns from investment in the forensic laboratory has been limited to the direct consequence of a conviction, ignoring other direct benefits (e.g., exoneration) and all indirect societal benefits. As an intelligence contribution, the HSFC analysis addressed the cases directly submitted to the laboratory and supplied intelligence towards the prevention or identification of other instances of impaired driving.

3.3.3. Miami-Dade

The Forensic Services Bureau (FSB) of the Miami-Dade Police Department (MDPD) addressed the dearth of front-end forensics through the creation of an intelligence analyst (IA) position in 2019 as a bridge between the crime laboratory and police investigators [19,117]. The IA tapped the resources of the FSB (e.g., ShotSpotter output with NIBIN, AFIS, and CODIS) and provided leads to investigators. With the addition of the first IA, a conservative estimate of the ROI from the front-end forensics provided benefits of USD 48:USD 1; that is, USD 48 is returned for each USD 1 expended.

The MDPD expanded the use of IAs, establishing two additional IA positions in 2021. MDPD secured grant funding in 2022 for an additional IA position for cold case investigations and forensic investigative genetic genealogy research. The rapid expansion of the IA program has been accompanied by a rapid expansion of the connections between big data sources to investigative leads. As the number of IA positions increased, so did the refinement of the IAs role. The activities of the initial IA hire highlighted in Delgado et al. [19] detailed how the IA extracted details from forensic databases, police databases, and social media to provide leads. Subsequent developments have led to the use of shared Power BI dashboards that permit investigators to quickly sort details from these databases. These developments move the IA role from a one-to-one relationship with investigators to a one-to-many relationship.

The Power BI dashboard puts more options into the hands of the investigators. Among the many data windows on the dashboard is a sortable screen with detailed NIBIN information, such as the number of NIBIN links for a given firearm along with the arrestee and associated case number. Another window ranks the firearms with the most NIBIN links. Another NIBIN window presents a persons involved list (victims, suspects, reporting persons, etc.) with the firearm's crime number, case numbers, and dates. Another NIBIN window highlights linked incidents with dates, type of crime, and location. Other windows on the same dashboard indicate CODIS hits and latent fingerprint identifications. Expanding investigations via the coordination of multiple databases creates forensic intelligence that addresses the focus of current investigations and unleashes connections to previously unimagined relationships [75]. This move to shared databases expands the power of the leads from those reported by the IA to additional searches by the investigators, bringing front-end forensics into greater use. The IA becomes the bridge to connect the participants in the justice system, solve existing investigations, and prevent future crime [45].

The forensic intelligence unit is involved in all gun violence discussions, general investigative unit best practices meetings, gang violence discussions, etc. The team is networked throughout MDPD as well as Miami-Dade County.

3.3.4. Phoenix

The Phoenix Police Department Crime Laboratory participated in a study of the contributions of a crime gun intelligence center (CGIC) [43,44,114]. The transition to a CGIC enhanced the front-end forensics by providing leads rather than waiting for a full analysis from a firearms analyst at the back end. The CGIC experiment changed many of the priorities in the analytical sequence of the laboratory. The intent was to input crime gun details into NIBIN as quickly as possible (24–48 h).

Among the lessons learned in the Phoenix study were the prioritization of analyses for a given item of evidence. For example, recovered firearms and casings may have DNA or latent fingerprint evidence in addition to firearms and ballistics detail. Although the intent of the CGIC was to input the firearms and ballistics details into the system as quickly as possible, delays in extraction of biologic evidence may result in the deterioration of potential evidentiary source. They learned that latent prints rarely were recovered from casings, so that process was ignored. However, firearms were generally swabbed first for DNA as a general procedure before test firing. When multiple casings were recovered, a single casing might be diverted from entry into NIBIN for DNA analysis to increase the number of profiles generated before potential deterioration from the metal surfaces.

In the review of the data from the project, the evaluation suggested the CGIC project was a success. However, one result left some doubts. The reviewers note that "we further examined the effect of the evidentiary value of the CGIC on clearance rates and prosecutorial outcomes for gun crimes. The results revealed that cases in the posttest period with a NIBIN lead had greater odds of an arrest when compared to those cases in the pretest period without a NIBIN lead. However, cases in the posttest period with a NIBIN lead were not significantly more likely to be charged or to result in a conviction" [43] (p. 547).

3.4. Measuring the Value of Forensic Science

Each of the forensic laboratory experiences in the prior sections offer examples of increases in front-end forensics. As with any business decision, each tactical change around a strategic initiative should be evaluated for success. As highlighted in Project FORESIGHT, success may be expressed as a more efficient allocation of the scarce resources of the crime laboratory towards meeting strategic objectives [133,134]. For each of these front-end forensic projects, a cost–benefit analysis with a determination of the return on investment will indicate whether the gains outweighed the costs of the project.

Measurement of the crime laboratory's value is complex. A partial measure of the contribution of the laboratory in the administration of justice is the marginal contribution towards conviction (e.g., [15]). Alternative measures of value include the avoidance of further crimes from the collection of data, such as the DNA database (e.g., [34,63,135]).

For a cost–benefit analysis of forensic sciences, the cost detail is readily available through Project FORESIGHT [6–14]. Although the FORESIGHT data are not differentiated by type of crime, the average cost of analysis for 21 areas of investigation is provided for a range of caseloads. Additionally, the corresponding level of staffing is noted for the same range of caseloads.

Benefits, however, are more difficult to express since the benefits come in the form of an opportunity cost avoided. The benefits tend to be crime specific in terms of the level of the direct and indirect costs and in terms of the probability of the crime occurring. As such, extrapolation of the costs avoided must come from a variety of event studies in the literature.

To illustrate the estimation process, consider an example of such a benefit determination in a review of the return on investment from testing the backlog of previously unsubmitted sexual assault kits (SAKs) [15]. They begin with a review of the literature on sexual assault and detail results for expected cost and probability of various outcomes. They argue that the gains from testing all SAKs comes from the prevention of additional assaults. From the criminology literature, they record the expected number of repeated sexual assaults from a serial rapist for a year and the number of years of activity for such assaults [136]. The literature also details the expected losses from various crimes to be used as the associated opportunity cost of the crime [137].

Next, observing the outcomes from several jurisdictional efforts to identify and test the backlog of previously unsubmitted SAKs, the relative frequency of DNA hits is used as a proxy for the probability of a hit in other populations. While the success metrics could have ended at this point, the particular measure of success, conviction, is measured. Table 1 highlights the estimation process. From the number of "hits," the already incarcerated cases were removed, as were "hits" where the victims recanted or were difficult to find, and finally, cases past the statute of limitations were removed from consideration. Even with this interpretation of success, the return on investment proved to be USD 81:USD 1; that is, the societal benefit was USD 81 for every USD 1 spent.

Table 1. Estimation of returns to backlogged SAK testing for each dollar spent [15].

P (DNA hit)	0.316
X	X
P (DNA hit leads to conviction)	0.037
X	X
Sexual assaults averted	26.22
X	X
Sexual assault victim cost and indirect costs	USD 435,412
Expected costs avoided	USD 133,671.00
divided by	/
Cost of DNA testing	USD 1641
Dollar returns per dollar spent	USD 81

The inclusion of such details on cost, cases, personnel, time, backlog, and turnaround time in the event studies on the SAK backlog permitted many more questions to be addressed than considered in the original studies. Indeed, another study expanded upon the analysis for a consideration of policies for the testing of de novo SAKs [16]. As with the prior study [15], a conservative approach is taken to lowball the ROI. Greater detail on the cost structure for crime laboratories suggests a much broader range of returns because of economies of scale [5–12]. If all SAKs are submitted to the laboratory for testing, then the ROI jumps to a USD 99:USD 1 for a very small caseload laboratory to as high as USD 646:USD 1 for a crime laboratory analyzing a case volume associated with perfect economies of scale.

Economies of scale refers to the efficient production of a good or service to its lowest cost level. There is a "right" size for the provision of each good or service. In for-profit industries, finding that optimal size is required for the survival of a business. In the public sector, price competition does not force a perfect economies of scale result. Nonetheless, as jurisdictions increase caseloads up to a point, there is a natural tendency for average costs to fall as efficiencies are achieved. Table 2 highlights the range of performance for Project FORESIGHT participants for the fiscal year 2022.

The wide-ranging performance in each area of investigation is primarily due to productivity differences as highlighted in Table 3.

Table 2. Cases Processed per USD 1000.

Area of Investigation	25th Percentile	Median	75th Percentile
Blood Alcohol	7.94	4.55	2.97
Crime Scene Investigation	0.66	0.25	0.13
Digital Evidence	0.65	0.37	0.19
DNA Casework	0.87	0.67	0.43
DNA Database	21.37	12.70	7.49
Document Examination	0.17	0.14	0.09
Drugs—Controlled Substances	3.47	2.46	1.99
Evidence Screening and Processing	1.66	1.05	0.86
Explosives	0.10	0.06	0.04
Fingerprints	1.27	0.93	0.68
Fingerprints Database (including IAFIS)	4.43	1.88	1.06
Fire Analysis	0.51	0.33	0.20
Firearms and Ballistics	0.70	0.42	0.28
Firearms Database (including NIBIN)	12.34	4.48	1.64
Forensic Pathology	0.50	0.48	0.44
Gun Shot Residue (GSR)	0.43	0.29	0.21
Marks and Impressions	0.17	0.14	0.11
Serology/Biology	1.19	0.85	0.51
Toxicology Antemortem (excluding BAC)	1.70	1.25	1.00
Toxicology Postmortem (excluding BAC)	1.57	1.11	0.98
Trace Evidence	0.23	0.17	0.10
			Source [14]

Table 3. Cases per FTE.

Area of Investigation	25th Percentile	Median	75th Percentile
Blood Alcohol	318.81	605.36	983.42
Crime Scene Investigation	15.69	45.55	75.67
Digital Evidence	26.25	42.65	87.53
DNA Casework	78.25	101.01	133.59
DNA Database	1204.89	2515.66	3702.91
Document Examination	16.46	21.02	26.55
Drugs—Controlled Substances	300.34	360.45	481.53
Evidence Screening and Processing	105.55	144.89	174.09
Explosives	5.57	7.65	11.22
Fingerprints	94.36	133.04	162.24
Fingerprints Database (including IAFIS)	216.73	327.22	549.55
Fire analysis	26.39	43.40	70.42
Firearms and Ballistics	45.00	63.83	112.37
Firearms Database (including NIBIN)	336.68	684.45	1092.16
Forensic Pathology	104.40	155.46	207.06
Gun Shot Residue (GSR)	26.50	34.15	57.80
Marks and Impressions	14.15	19.07	27.22
Serology/Biology	58.49	112.67	144.92
Toxicology Antemortem (excluding BAC)	139.86	185.54	266.83
Toxicology Postmortem (excluding BAC)	138.41	169.06	202.56
Trace Evidence	29.76	33.70	38.50
			Source [14]

A more detailed depiction of the average cost of processing a case is illustrated for DNA casework in Figure 1. Notice that the minimum cost (perfect economies of scale) is associated with a caseload just under 10,000 cases processed per year. The reduction in average cost up to that point is largely the result of productivity increases as highlighted in Figure 2, which shows the average number of cases processed per full-time equivalent employee (FTE).

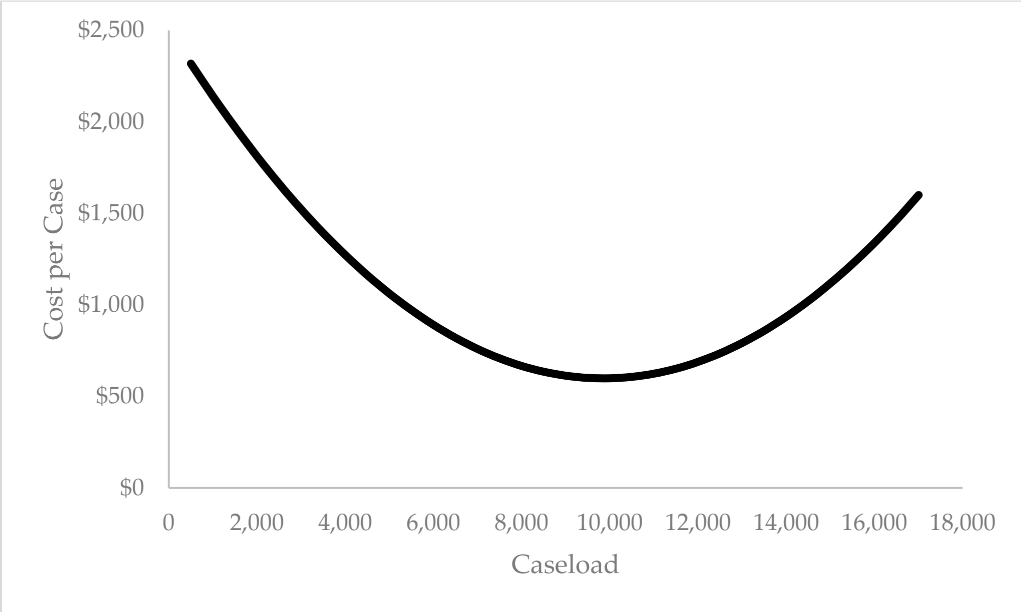

Figure 1. DNA casework and economies of scale [14].

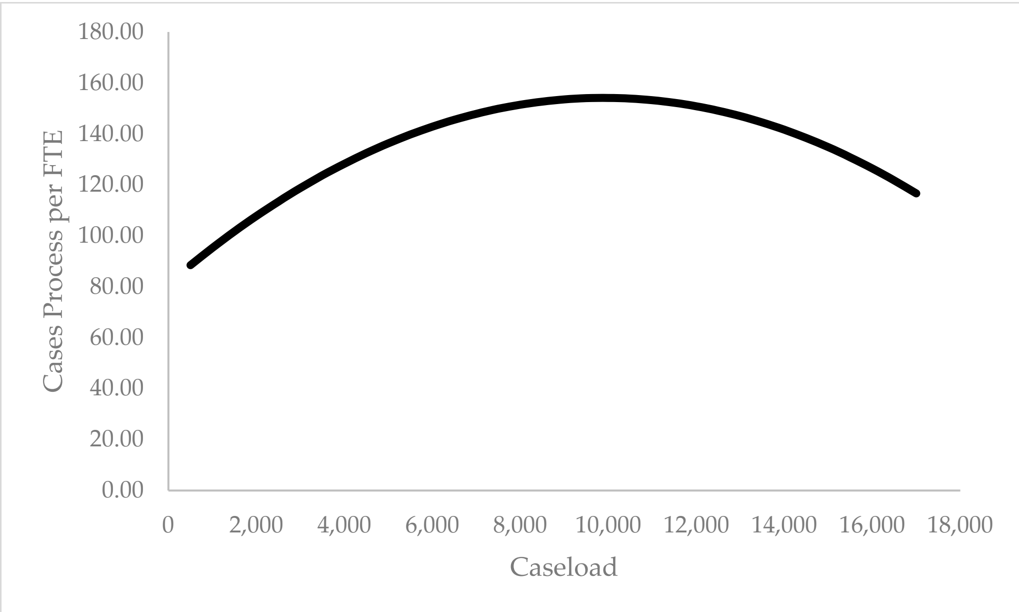

Figure 2. DNA casework and productivity [14].

This same event study data has been extended for evaluation of rapid DNA technology [17]. Combining the aforementioned data with the event data from the Kentucky State Police Forensic Laboratory demonstrated a return of USD 390:USD 1, which provided the justification for the long-term funding of the technology.

4. Discussion

Forensic intelligence offers the opportunity to unleash the potential contribution from forensic science. As noted elsewhere, "forensic science has primarily positioned itself as a service provider for the criminal justice system, following the dominant and traditional reactive law enforcement model. Unfortunately, this focus has limited its capacity to provide knowledge about crime systems and to support other forms of policing styles through forensic intelligence" [52].

What is the value of forensic science? This simple question requires a complex answer. There exist as many responses as there are beneficiaries of the justice system. Value is a measure of success, and success may be represented by convictions, exonerations, prevention, contributions to public safety or public health, reduced recidivism, and other interpretations of success [138]. When a crime is committed, the "cost" of that crime involves both direct and indirect costs. The direct costs include damages and recovery expenses of the victims of the crime. The indirect costs extend to lost opportunities, increased safety expenditures, and productivity losses, among other costs. The contribution of forensic science from crime laboratories, medical examiners, and coroners follows from the avoidance of these costs.

To simplify the examination of value, cost–benefit studies tend to concentrate on the role of forensic science in convictions as a lower limit measure of benefits. Such an approach, while enlightening, limits the contribution of forensic science to the back-end of the justice system. The recent surge in the literature noting the front-end contributions of forensic science as a source of leads to investigators opens up the opportunity to measure this additional source of value. Are we capturing the outcomes when the laboratory analysis refocuses the investigation away from previous suspects? Is the avoidance of having someone wrongly accused less valuable than the science that leads to the prosecution of the actual perpetrator of a crime? The societal cost can be calculated for all concerns [139]. Similar techniques may be applied to either scenario, but the data must be captured and reported to measure each supporting outcome.

The complexity of the sources of value suggests that the determination of value may be too large a study to undertake as a single project. Instead, the contributions from other examples of strategic implementation may offer pieces of evidence of value. Consider the incremental contributions highlighted above. In the case of the testing of SAKs, the conservative baseline measure of the contribution from testing all previously unsubmitted SAKs offered a ROI of USD 81:USD 1, as highlighted in Figure 1 [15]. The incremental extension of that analysis to new sexual assault cases with immediate submission of SAKs, jumped the ROI to as high as USD 646:USD 1, as highlighted in Figure 2 and Table 1 [16]. Additional analysis shows the ROI contributions from rapid DNA testing of SAKs or "test all" SAK policies [17,140]. The inclusion of the indirect impacts from the forensic intelligence contributions of forensic databases provides additional benefits through reduced recidivism [34,42,64,135].

Consider the contributions from the experiences of Arkansas, Houston, Miami-Dade, and Phoenix. Each of these examples offers a direct analysis of the success or failure for that particular jurisdiction, but also offers some projections for other jurisdictions considering similar tactical operations.

The Arkansas State Police Crime Laboratory implemented a Lean Six Sigma program as a means to increase personnel flexibility and reduce backlogs and the corresponding turnaround times. The ROI impact is measured in time savings, public health, and laboratory productivity. The Lean Six Sigma program began with the toxicology sections during a period of dramatic increases in the use of emerging drugs, particularly the rise in contributions from fentanyl. Reduced turnaround times lead to increased identification of trends, resulting in public health efforts measured in saved lives [139].

The Houston experience offers a similar contribution through the sentinel role that identification of emerging trends in impaired driving offers to public health and safety. The contributions may be measured through avoidance of accidents and the associated losses to death, injury, and property [40]. Ropero Miller et al. [40] note that the liberalization of drug laws via legalization or decriminalization increases the expected number of drug-related accidents. The corresponding average cost from additional accidents ranges from USD 12,521 for property damage to USD 98,998 for injury to USD 9,984,261 for fatalities. Vigorous enforcement through greater investment in policing and associated laboratory support reduces the probabilities of drug-related accidents.

The Phoenix GCIC experiment produced faster results, which offered leads for crimes with high repeat offenders [138]. The commitment to speedy entries of firearms and ballistics details into NIBIN, provided a 163% increase in NIBIN leads and increases in clearance rates [43]. The time savings for clearances provide direct cost savings in investigations, increasing the ROI. The process change for increased leads also provided procedural changes within the laboratory with updated procedures for DNA analysis and latent print examination.

The Miami-Dade experience put many prior suggestions into practice. The initial spider graphs followed theoretical suggestions and provided links to present and former crimes [33]. The persistence of the IA model permitted the laboratory to overcome the cultural problems inherent between policing cultures and laboratory cultures [28]. By combining the use of the big data sources in forensics with social media and policing databases, the IA model offers a flexible perspective to increase the value of both the laboratory and police and the overall ROI from the justice system [45,46].

This sample of innovations from these jurisdictions offers some insights into strategic initiatives enacted in other jurisdictions. While these operations are taken for the benefit of that jurisdiction, the potential lessons for other jurisdictions benefit the entire forensic science community. As such, documentation and sharing of information become critical to achieving all of the benefits available. Documenting and sharing the pre- and post-project impacts is critical to achieving the wide-ranging results that are possible. Sharing the outcomes with turnaround times, direct and indirect costs (capital, personnel, consumable, and overhead expenditures), backlog impacts, personnel allocation, types of cases, caseloads, sampling and testing details, and other perceived changes will facilitate the subsequent analysis of the strategic change for the laboratory and permit extensions and implications for others.

With these contributions, a better response will emerge when responding to the question of the value of forensic science. Ultimately, these values will form the foundation of the response to funding bodies for the distribution of public funds towards their highest valued use. Without such a response, forensic laboratories are bound to be underfunded.

Funding: This work was supported, in part, by the Forensic Technology Center of Excellence (Award 15PNIJ-21-GK-02192-MUMU), awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Project FORESIGHT annual benchmark data are available through the West Virginia University Research Repository [5–14].

Conflicts of Interest: The author serves as the Principal Investigator for Project FORESIGHT, a free, voluntary data submission of casework, personnel allocation, and financials by forensic laboratories. This work was supported, in part, by the Forensic Technology Center of Excellence (Award 15PNIJ-21-GK-02192-MUMU), awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice.

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