RESEARCH ARTICLE

The Return on Investment from Rapid DNA Testing of Sexual Assault Kits: The Kentucky State Police Forensic Laboratory Experience

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Abstract

The growing queue for DNA analysis in crime laboratories has prevented the analysis from providing investigative leads as turnaround time has grown, limiting the analytical results to a confirmatory role in the courtroom. Rapid DNA technology offers an opportunity to employ an automated system for the development of a DNA profile. The Rapid DNA technology permits a police booking station to take a buccal swab obtained from an arrestee, acquire a DNA profile, and test that profile against a DNA database, all while the arrestee remains in police custody during the booking process. Rapid DNA technologies are a capital-intensive system enabling sophisticated equipment designed for operation by individuals with limited technical training to provide investigative leads with immediate support. We present the testing of rapid DNA technology in a trial program conducted by the Kentucky State Police Forensic Laboratory. The Kentucky test confirms the efficacy of the rapid DNA testing as consistent with the findings from traditional laboratory testing. The economic analysis related to testing indicates that the time saving from the rapid DNA analysis yields benefits that far outweigh the costs from the change in technology.

Keywords: Rapid DNA; DNA analysis; cost-benefit analysis; return on investment; sexual assault

1. Introduction

Advancements in science undergo detailed scrutiny from many directions. New techniques require independent scientific verification of the efficacy of the technique. Ethicists evaluate the ethical and moral implications. Economists and business professionals consider the costs versus the benefits of advancements. In this manuscript, we consider the last of these examinations in the review of the application of one such scientific advancement—the deployment of Rapid DNA technology by the Kentucky State Police Forensic Laboratory System to reduce turnaround time (TAT) in DNA analysis of sexual assault kits (SAKs).

Rapid DNA technology offers an opportunity to employ an automated system for the development of a DNA profile. The Rapid DNA technology permits a police booking station to take a buccal swab obtained from an arrestee, acquire a DNA profile, and test that profile against a DNA database, all while the arrestee remains in police custody during the booking process. Rapid DNA technologies are a capital-intensive system enabling sophisticated equipment designed to be operated by individuals with limited technical training to provide investigative leads with immediate support.[1]

The use of traditional DNA analysis by forensic laboratories has grown over the past few decades in support of court cases.[2-4] That growth in demand for DNA analysis has not been matched by a concurrent growth in resources to forensic laboratories.[5,6] As DNA evidence provides greater support in the prosecution of crime, there has been an expansion in the categories of crimes for which police and prosecutors request DNA analysis. Without the corresponding growth in resources, laboratory TATs expanded. The growing queue for DNA analysis has prevented the analysis from providing investigative leads as TAT has grown, limiting the analytical results to a confirmatory role in the courtroom.

The introduction of Rapid DNA technology offers an opportunity to reprise the role of DNA analysis towards providing investigative leads. Several questions emerge with this technology. Primary among the questions is whether the technology offers a viable alternative and how the quality of rapid DNA technology compares to traditional DNA analysis. Second, review of the various Rapid DNA technologies must determine whether the expense of the rapid DNA technology and the corresponding reduction in TAT offers a cost-effective alternative to traditional laboratory testing.

Our presentation begins with a brief overview of rapid DNA technology. Next, the magnitude of the U.S. problem from unsubmitted and untested SAKs is described along with the impacts on forensic laboratories. The economic impact from the testing of the backlog of SAKs describes the benefit measurement. With this background detail, we present the testing of rapid DNA technology in the Kentucky trial. The Kentucky test confirms the efficacy of the rapid DNA testing as consistent with the findings from traditional laboratory testing.[7] The economic analysis related to *de novo* SAK testing indicates that the time saving from the rapid DNA analysis yields benefits that far outweigh the costs from the change in technology.[8-10] Following the results from the Kentucky State Police Forensic Laboratory, some implications for expansion of the technology are outlined.

2. Rapid DNA

Forensic DNA analysis is primarily conducted by public sector laboratories with some private laboratories conducting forensic analysis that has been outsourced from the public sector. While the private laboratories designate a price for their services, public laboratories generally do not charge police or prosecutors for their services. Instead, the queuing time to receive results becomes the *de facto* rationing mechanism. As that queuing time has increased over the years, the capabilities of DNA analysis to provide investigative leads to policing agencies has diminished and most DNA analysis has been relegated to courtroom support. Rapid DNA technology has been suggested as an alternative to traditional DNA analysis to reduce the wait time through capital investments to provide high quality results. The Federal Bureau of Investigation (FBI) describes the technology as:

> "Rapid DNA, or Rapid DNA analysis, is a term used to describe the fully automated (hands free) process of developing a DNA profile from a reference sample buccal (cheek) swab without human intervention. The goal of the FBI's Rapid DNA initiative is to link FBI approved commercial instruments capable of producing a CODIS core loci DNA profile within two hours to the existing CODIS infrastructure in order to search unsolved crimes of special concern while a qualifying arrestee is in police custody during the booking process."[11]

The Scientific Working Group for DNA Analysis Methods (SWGDAM) and others assisted the FBI in the evaluation of standards for approval for Rapid DNA systems. As of this writing, two systems received FBI approval for compliance with the National DNA Index System (NDIS), the database of the Combined DNA Index System (CODIS). The first approved systems is the ANDE 6C Series G, effective February 1, 2021. The second approved system effective July 1, 2021 is Applied Biosystems™ RapidHIT™ ID DNA Booking System v1.0. The Kentucky State Police trial used the ANDE 6C with the Rapid DNA testing of SAKs as described in the sections to follow.

3. The National Problem of Untested SAKs

An increased demand for DNA analysis is a phenomenon common to forensic DNA laboratories worldwide. In the United States, the backlog problem for DNA analysis is exacerbated by the revelation that many jurisdictions had warehoused SAKs, failing to send them to the crime laboratory for analysis.[12-16] Recent estimates suggest that even with efforts of the last several years to discover and test these warehoused SAKs, some 300,000 to 400,000 untested SAKs remain.[17] The U.S. problem is widespread and includes the state of Kentucky. Additionally, Kentucky is among the jurisdictions where the legislative body has mandated the testing of all the untested SAKs.

The revelation of the magnitude of warehoused SAKs across jurisdictions had the potential to overwhelm completely the capabilities for DNA analysis. Questions arose if the benefits from testing all kits would justify the costs. Beyond moral and ethical arguments to test, economic analyses surfaced to compare the social benefits with the economic costs for policing, laboratory analysis, and prosecution. Effective use of forensic databases, including NDIS, is amongst the most cost-effective methods to reduce crime.[18] The simple knowledge that biological evidence left behind during the commission of a crime may provide the lead to a specific perpetrator has a significant deterrence effect in reducing crime. A single addition to the DNA database may provide a societal benefit as high as $20,000.[19] The database benefits are most dramatic in reducing sexual assault where econometric analysis suggests that a one percent increase in submissions to the DNA database leads to a 2.7% decline in sexual assaults.[20] These studies suggest that investment through increased submissions to the database provide a highly cost-effective method to deter crime.

While additions to the DNA database may be more effective at deterring crime than investments in additional police or more police vehicles, the question remains whether the benefits from these investments exceed their costs. A review of several of the early attempts to discover the magnitude of the SAK warehousing problem indicated that testing the backlog of all SAKs yields a high return on investment (ROI).[21] Wang & Wein's (2018) comparison of the costs versus the benefits from testing all the warehoused SAKs takes a conservative approach to measuring the societal ROI. They use prior studies of serial rapists who had never been caught (and beyond the statutes of limitation) to estimate the relative frequency of sexual assaults.[22] The frequency of assaults combined with the average societal cost (i.e., the cost to the survivor and to others) from an assault provides the expected cost from a sexual assault.[23] The potential benefit from testing all of the warehoused SAKs is the avoidance of multiple assaults and a dollar benefit of $133,484. When compared to a conservative estimate of the cost of DNA testing, a conservative estimate of the benefit to cost ratio is $81.34 for every dollar spent.[21] This high rate of return provides the economic support to test all SAK programs recently enacted in many jurisdictions.[24,25]

4. The Kentucky Trial with Rapid DNA

4.1 Trial Description

As in many states, Kentucky requires all sexual assault kits submitted to the laboratory be tested, which increased the caseload as well as the TAT to obtain results. The caseload and TAT pressure increase with legislative mandates, including in Kentucky, where required testing led to problems of manpower, as the Kentucky State Police forensic laboratories did not have enough personnel to keep up with the DNA caseload. The complicated mixtures in sexual assault DNA casework extends the time problem as these difficult mixtures take significant time to interpret.

The increased caseload and TAT growth led to a pilot program with 100 rapid DNA kits provided to sexual assault nurse examiners (SANEs) in three jurisdictions in Kentucky for collection during forensic sexual assault exams. As the first CODIS approved laboratory to analyze sexual assault evidence on the Rapid DNA instrument, there were no prior validations for reference other than the company's own developmental validation. Development of protocols, training programs, and policies started from square one. While the pilot project provided the laboratory with valuable experience and data, all kits were tested and over half contained no suspect DNA.

At the time the SANE collected evidence for the traditional sexual assault kit, the SANE followed the Rapid DNA protocol and collected two additional swabs for the Rapid DNA kit. The kit included victim standards, which could be buccal (inside of cheeks), blood, or hair (pubic and/or head). Then, depending upon the victim statements of the assault, the SAK could include swabs from oral, external genitalia (vaginal or penile), internal (vaginal and/or anal), fingernails, underwear, or secretions on bodily surfaces.

Prior to packaging the SAK for traditional testing and the separate swabs for Rapid DNA analysis, the swabs were placed in a dryer. The Rapid kits were delivered directly to the laboratory while the traditional kit went to law enforcement, where evidence technicians submitted data through regular channels for traditional DNA analysis. Rapid kits were tested once they came into the laboratory and any suspect profiles obtained were searched against a copy of the state database in the FAIRS software.[26][i]

Analysts were trained either as technicians performing the pre-processing steps for samples and instrument operation or as analysts analyzing the data and subsequently writing reports. Analysts received training from ANDE as well as internal training, including mock cases and mock trials. The intent of the program was to lower the TAT as taking advantage of the speed of the instrument was paramount.

Once the samples were loaded, the instrument handled the rest of the analysis, which allowed analysts to work on other things. The entire process from beginning to end lasted less than two hours.

4.2 Trial Outcomes

The results from the trial provided some immediate benefits. Table 1 summarizes the laboratory Rapid DNA findings and the follow up analysis of the SAK via traditional testing.

Table 1: Rapid DNA and Traditional DNA Analysis Outcomes

Rapid DNA Analysis		**Traditional DNA Analysis**	
Profile Obtained	14	Profile Obtained	14
Mixture Obtained	7	Profile Obtained (2 underwear, 1 external genital swab)	4
		Mixture	1
		Not Tested	2
No DNA foreign to victim	58	Profile Obtained (5 neck swab, 2 oral swab, 1 breast swab, 1 abdomen swab, 1 condom swab)	12
		Mixture (1 Underwear, 2 breast swabs, 1 penile swab)	5
		Pending	1
		No Foreign DNA	13
		Too Limited	7
		Not Tested	20
No DNA	9	Mixture	2
		No Foreign DNA	1
		Too Limited	1
		Not Tested	5

The data in Table 1 show that there were four outcomes from the Rapid DNA analysis: Profile obtained, Mixture obtained; No DNA foreign to victim; or no DNA obtained. The respective counting for each Rapid DNA outcome appears in the second column. The final two columns highlight the results from traditional DNA testing (if tested) and the corresponding count for that category. Because the Rapid DNA testing was limited to one of two swabs taking during the victim examination, it is not surprising that the traditional DNA analysis was able to obtain a few additional profiles from the larger amount of evidence in the SAK.

Consider the outcomes from the Rapid DNA analysis. The intent of the testing and comparison to the DNA database comes through a DNA identification of a perpetrator, either a match to an existing suspect or a match to a stranger. In one case of the seven where a mixture resulted from the analysis, there was a hit in the database to a stranger, who had not been an identified suspect in the assault. For the 14 samples where a profile was obtained, 10 profiles were not in the database, but four additional hits to the database resulted. Two of the hits matched suspects and the other two hits matched strangers in the database.

What is the value of those five hits and does it justify the adoption of Rapid DNA technology? Certainly, there is great value in the scientific verification of the technology. As a controlled experiment with specific additional swabs drawn for Rapid DNA testing, additional testing may be applied to a different selection of SAK samples for testing. Recent research suggests that machine-learning selection of SAK elements outperform medical expertise in the selection of the most productive swabs in the SAK.[27]

The trial also included a capture of the time of the assault, the time the Rapid DNA analysis was completed, and the time that the traditional DNA analysis was completed. Although the intent of the Rapid DNA technology calls for buccal swabs of arrestees with immediate use of the Rapid DNA machines at the booking facility with the expectation of a two-hour (or less) TAT to occur while a suspect is held. For the Kentucky State Police Forensic Laboratory trial, the time from SANE evidence collection to transport to the laboratory took longer than the two-hour time period with an average TAT of 9 days. The traditional testing had an average TAT of 270 days. For the Kentucky laboratory experience, the Rapid DNA testing cost roughly $2,450 compared to traditional testing at $2,000.[28] The benefit comes through costs avoided to victims and society through the prevention of additional crimes, including additional sexual assaults.

As noted previously, there is a high activity level by rapists, where an average of 7.1 assaults per year occur over the period of sexual assault activity. With the 261-day saving in the TAT from the adoption of Rapid DNA technology over traditional DNA testing, an average prevention of 5 additional sexual assaults per hit represents the savings. With the 5 hits from the Rapid DNA experiment, then the expected savings are found in the expected prevention of 25 sexual assaults.

5. Forensic Laboratories DNA Analysis: Cost, Backlog, and TAT growth

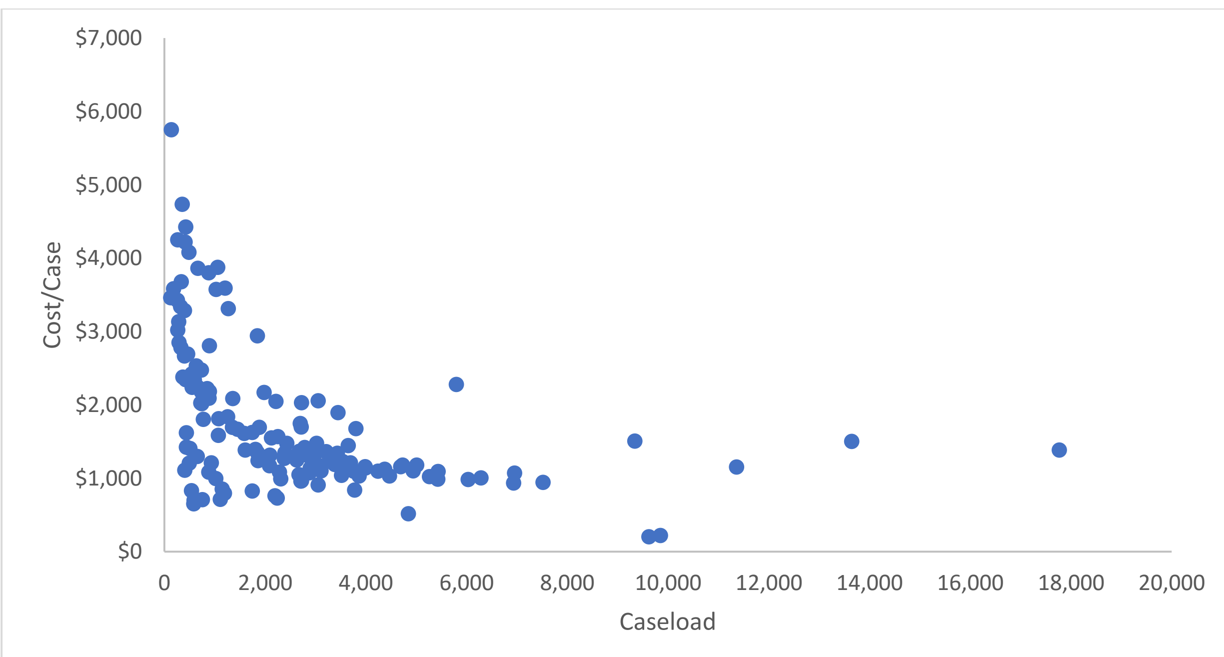
The impetus for the Kentucky State Police Forensic Laboratory rapid DNA trial followed from the forensic laboratory's experience with backlogged DNA cases. While the increased TAT for sexual assault cases receives attention, the backlog growth comes through evidence submitted from a variety of crimes, where each request for

DNA analysis added to the queue of cases to analyze. The success of DNA evidence to provide unique identifiers, coupled with the CSI effect on courtroom expectations for case support via DNA analysis, has fed the demand to the laboratory for cases from violent crimes, such as homicides and sexual assaults, to various property crimes where blood, saliva, or touch DNA remain behind at the crime scene.

Over the period from 2015-2020, the average cost for a forensic laboratory DNA case fell 38% and the corresponding average cost of a sample within a case fell by 29%.[29-34, ii] While costs were falling, the demand for services increased dramatically, but laboratory resources did not grow to meet that increased demand. As a result TAT increased by 61% from 2015 to 2020 and the percent of backlogged cases grew by 590%.[iii]

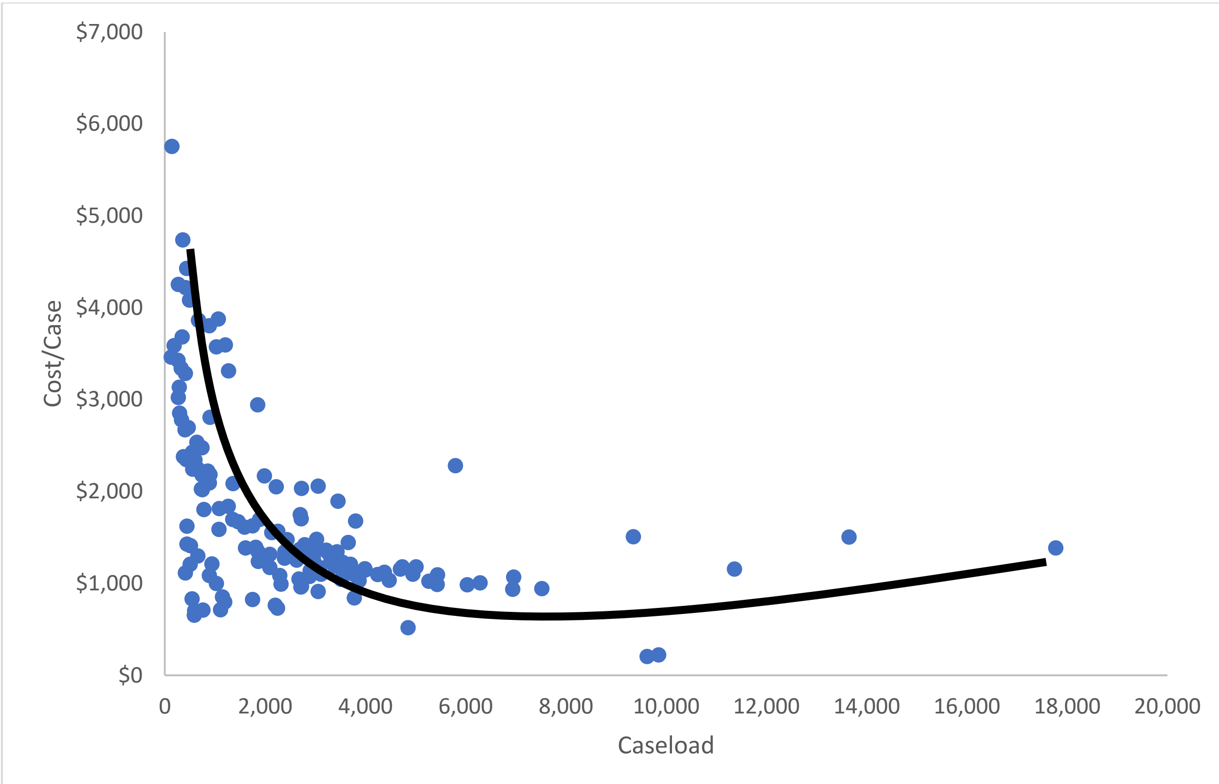
The decline in average costs for processing cases and samples bears closer inspection. Figure 1 illustrates the fiscal year 2020 DNA Casework analysis for laboratories submitting data to Project FORESIGHT.[34] Each point in Figure 1 represents a single laboratory's cost/case relative to caseload for DNA analysis. The plot suggests a U-shaped relationship, where average cost declines as caseload increases, but up to a point. After achieving some optimal caseload level, a minimum average cost is reached and thereafter average costs begin to rise.

Figure 1: DNA Casework Cost/Case v. Caseload[17]



This is a representation of the economic concept of economies of scale. Since political jurisdictions, served by public forensic laboratories, dictate caseload, market forces do not lead to perfect economies of scale (i.e., the minimum point for average cost). This suggests that the vast majority of forensic laboratories will experience declining costs as caseloads increase over time. Figure 2 includes an econometric estimate of the economies of scale relationship we can anticipate as caseload changes over time with increased demand for DNA analysis.

Figure 2: DNA Casework Efficient Frontier



The importance of this cost to caseload relationship comes as the cost-benefit relationship is analyzed. While the prior suggestion of an $81:$1 benefit to cost ratio was found for testing the backlog of SAKs, the benefit to cost ratio for rapid DNA depends upon where a laboratory operates along the curve in Figure 2. Even though this ratio is large, since the laboratory competes with all other uses of public funds, the higher net benefits and lower costs associated with perfect economies of scale can make the difference in the level of funding received. Notice from Figure 2 that few laboratories have come close to the caseload associated with perfect economies of scale. As testing is expanded most laboratories will continue to achieve greater economies of scale and experience a greater benefit to cost ratio.

6. The Returns to SAK Testing Under "Test All" Laws

The benefit to cost ratio from testing the backlog of SAKs suggested a benefit to cost ratio of approximately $81:$1 as justification for the testing of all previously unsubmitted SAKs. The revelation of the magnitude of the warehousing of SAKs has led many jurisdictions, including the state of Kentucky, to mandate testing of all SAKs moving forward. These *de novo* cases have a much higher ROI than found with the testing of backlogged cases. The higher ROI is a product of both greater benefits and lower costs of testing.

The higher societal benefits come from several sources. First, "test all" policies increase the number of profiles added to DNA databases. Each submission to the DNA database provides a deterrent towards future sexual assaults. The submission increases the potential societal benefit.[19,20] Additionally, the analysis leading to the approximately $81:$1 benefit to cost ratio from testing the backlog included the testing of SAKs that extended beyond the statute of limitations.[36] Test all programs for *de novo* cases have a heightened probability of a DNA database hit, which raises the probability of a database match from 3.7% in backlogged cases to 28.76% in *de novo* cases.[37]

An additional update to the expected benefit from testing *de novo* SAKs comes with an update of the dollar benefit when accounting for inflationary effects over time. The benefits projected by DeLisi, et al. (2010) used 2008 dollars. When these benefits are inflation-adjusted and updated to current dollars, the expected benefit grows to $558,916 for each sexual assault averted.[38] When coupled with the higher probability of a DNA database hit, the ROI from testing is dramatic.

Combining this higher benefit from testing with the economies of scale from increased testing yields a strong argument for greater investment in rapid DNA technology. The size of the benefit depends upon the DNA caseload as shown in Figure 2. For example, consider the expected average cost of laboratories analyzing 200 DNA cases, 1,000 DNA cases, or 10,000 DNA cases. The corresponding expected cost per case would be $3,090 for the 200 caseload, $1,806 for the 1,000 caseload, but falls to $838 for the 10,000 caseload.[34] If the Rapid DNA adoption leads to the identification and incarceration of the alleged assaulter for just one year, the corresponding benefit to cost ratios would be $181:$1, $309:$1, and $667:$1, respectively.

7. ROI and Policy Change for the Kentucky State Police Forensic Laboratory

The trial convinced the State of Kentucky to adopt the Rapid DNA technology for a variety of crimes moving forward. The current Kentucky State Police Forensic Laboratory annual caseload of DNA cases is approximately 2,000 annual cases, which implies a benefit to cost ratio of $390:$1. As the use of Rapid DNA expands beyond the trial phase, the benefit to cost ratio should increase as the laboratory achieves additional economies of scale.

For sexual assault cases, implementation of Y-screening, not previously used by the Kentucky State Police Forensic Laboratory, became part of the workflow to identify those kits suitable for Rapid DNA and those that required traditional DNA analysis. The ANDE 6C is much faster than traditional testing. The pre-treatment step prior to loading samples on the instrument permits the separation of the female and male DNA. The Y-screening quantitates the amount of male DNA. The new policy requires 5ng or more of male DNA to qualify for Rapid DNA; otherwise, samples containing less than 5ng were routed for traditional DNA testing.

The success of the trial in confirming the reliability of the Rapid DNA technology has led to an expansion of the technology in the Kentucky State Police system. The expansion includes additional personnel in the form of technicians, DNA analyst, and technical administrative reviewers. Additional personnel at the police academy meet this expansion in the deployment of the Rapid DNA equipment.

Updated policies include an expansion in the use of Rapid DNA technology beyond sexual assault cases to include some murder, robbery, assault, and property crimes. To be accepted for Rapid DNA testing, cases could come from bloodstains (or suspected bloodstains) or saliva (or suspected saliva). Additional applications include the identification of human remains with a comparison to a known reference sample or compared to the DNA database.

The updated policies enables the forensic laboratory to adopt a more substantial role in providing leads in the investigation of crime. With the growth in TAT for DNA casework, the forensic laboratory's role had been relegated to courtroom support. The Rapid DNA technology follows the concept of intelligence led policing, where the forensic laboratory may assist the early stages of an investigation to point towards or away from various suspects. This heightens the value of the DNA database towards solving crimes currently under investigation and perhaps linking individual to other unsolved crimes.

8. Conclusions

The application of Rapid DNA technology shows great promise in addressing the problem from the growing TAT in DNA casework. The cost-benefit analysis supports the technology as a high net benefit use of public funds and offers policymakers solid metrics for comparison with other uses of limited jurisdictional budgets. In States permitting DNA samples from arrestees, the expansion the use of the technology to booking stations offers large benefits as the DNA database grows.[19]

As the use of forensic intelligence grows towards the provision of more leads, the DNA database will grow as a supporting investigative tool, such as has happened with the expanded use of other forensic databases to investigative leads.[39,40] The Kentucky trial had firm protocols for the selection of which SAK swab to test. Recent DNA analysis has suggested that a machine learning prioritization will dramatically expand the number of CODIS hits.[27]

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[i] The mirrored copy of the state DNA database resides on a standalone laptop with access restricted to CODIS analysts. The mirrored copy is updated and searched on a weekly basis.

[ii] "A case in an investigative area refers to a request from a crime laboratory customer that includes forensic investigation in that investigative area." "A sample refers to an item of evidence or a portion of an item of evidence that generates a reported result."[34]

[iii] "Although no official definition exists for the DNA backlog, the National Institute of Justice (NIJ) defines a backlogged case as one that remains untested for 30 days after it has been submitted to a laboratory".[35]

