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A Landscape Study of Laboratory Information Management Systems (LIMS) for Forensic Crime Laboratories

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Report Overview

The National Institute of Justice (NIJ)'s Forensic Technology Center of Excellence (FTCoE) at RTI International worked with a variety of forensic crime laboratory personnel, including crime laboratory directors, unit chiefs, laboratory information management system (LIMS) administrators, information technology (IT) professionals, and analysts, to perform this landscape study of available LIMS systems, and their adoption.

The FTCoE strives to provide valuable resources that promote the use of technologies in the forensic community. A landscape study is a comprehensive overview of market participants, their products including insight on features to inform purchasing decisions and future adoption. This report gives a comprehensive look at the benefits of having a LIMS, the range of solutions available, and guidelines for successful LIMS implementation.

Insights from the NIJ's Report to Congress: Needs Assessment of Forensics Laboratories and Medical Examiner/Coroner Offices helped lead the FTCoE to conduct this landscape study:

- LIMS can enable systems-level communication in forensic science, a key community need.
- Beyond its basic functions, LIMS vendors offer advanced features that provide significant benefits that improve the laboratory's operations and communications with stakeholders. However, these value-added features are not widely implemented. For example, of approximately 90% of the publicly funded laboratories who use a LIMS, less than a third of them use LIMS functions that track criminal case status or interface with laboratory instrumentation.
- Successful implementation of any LIMS requires understanding and balancing the needs of multiple types of laboratory personnel, including evidence controllers, forensic examiners, section managers and technical leaders, quality managers, chief information officers, and senior leadership.

Landscape Study Objectives

This landscape report provides crime laboratory directors, crime laboratory personnel, law enforcement agencies, prosecutors, courts, and other stakeholders and end users with the following:

- Background information on LIMS and their integration into the laboratory evidence management process
- The product landscape of select commercial off-the-shelf (COTS) LIMS products
- Considerations for implementing or updating internally developed and COTS LIMS
- Use profiles from end users illustrating best practices and lessons learned from incorporating a LIMS into the laboratory workflow.
- LIMS features that facilitate systems-based communications between crime laboratories and their stakeholders, such as tracking status of criminal cases and the associated lab work.

Landscape Methodology

To conduct this study, the FTCoE used a process that included:

- Consulting secondary sources—including laboratory manuals, journals, federal reports (including the NIJ's Report to Congress: Needs Assessment of Forensic Laboratories and Medical/Coroner Offices,)[1] and industry literature—to obtain information on key LIMS providers, successful use cases, and implementation considerations for these systems.
- Discussing with varied state and local crime labs across the U.S., the use and implementation of COTS and internally developed LIMS, ultimately gaining insight from varied perspectives including laboratory directors, unit chiefs, LIMS administrators, IT professionals, and analysts.

[1] U.S. Department of Justice (DOJ), Office of Justice Programs (OJP) National Institute of Justice (NIJ). (2019). Report to Congress: Needs Assessment of Forensic Laboratories and Medical Examiner/Coroner Offices. https://www.justice.gov/olp/page/file/1228306/download

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Executive Summary

As a key stakeholder in the criminal justice system, forensic laboratories must track, analyze, and report on evidence related to each request for service they receive. This is no easy task for laboratories: according to a 2014 survey by the Department of Justice's Bureau of Justice Statistics (BJS), publicly funded crime laboratories received nearly 3.8 million requests for forensic services, with an average of 93,000 requests per laboratory.[2] The high number of caseloads necessitate the use of technology to ensure integrity of evidence is maintained and laboratories are operating efficiently. Laboratory information management systems (LIMS) were developed to solve many of these challenges. LIMS is a database management system (DBMS) that collects, creates, and stores all data related to forensic examinations in a crime laboratory. LIMS enables the forensic laboratory to efficiently manage evidence and resources and can be scaled to meet the demands of federal, state, county, and municipal laboratories.

> "LIMS is an investment that will pay massive dividends down the road in terms of improved efficiency and quality of work product. Like all investments, there is required up front efforts which must be supported and led by lab directors."
>
> —Dr. Ray Wickenheiser, DPS, MBA FAAFS, Director, New York State Police (NYSP) Crime Laboratory System

The 2009 BJS Census for Publicly Funded Forensic Crime Laboratories shows that approximately 84% of crime laboratories use LIMS. 97% of state laboratory systems, 76% of county laboratories and 56% of municipal laboratories have a LIMS.[2]

Most LIMS contain basic features that document information related to a case, such as the chain of custody, manage laboratory processes and resources, maintain data integrity and security, and generate automated and electronic reports for internal and external stakeholders. LIMS also offer advanced features that improve information flow within the laboratory as well as to and from criminal justice stakeholders.

A laboratory has several options to implementing a LIMS that addresses their needs: vendors offer commercial off-the-shelf (COTS) products, or laboratories can develop their own system to be as simple or complex as they need it. This report breaks down advantages and disadvantages of both options and provides an overview of key features offered by a selection of major vendors in the LIMS space.

Adopting a LIMS may be as disruptive and transformative as going through ISO 17025 accreditation and may reveal ambiguities in laboratory policies and expose inconsistencies in team practices. Before implementing LIMS, laboratories must understand there is a significant amount of front-end planning and time necessary to design the software to its needs. Even if using a COTS LIMS, it must be refined for use in a specific laboratory. This planning process includes developing and understanding two key factors:

Needs of LIMS end users: Stakeholders in the criminal justice system use LIMS in a variety of different ways, depending upon their role in the organization, and thus, they have different needs for a system. Decision makers must consider these stakeholders and their needs before implementing or significantly upgrading a LIMS. Key questions provided in the report are important to work through with all stakeholders, including laboratory leaders and practitioners, before choosing and implementing a LIMS. It is important to keep in mind that implementation is not merely an information technology (IT) project, and success hinges on the engagement of leadership and users through the process.

[2] Durose, M. R., Walsh, K. A., & Burch, A. M. (2012, August). *Census of Publicly Funded Forensic Crime Laboratories, 2009*. NCJ 238252. U.S. Department of Justice, Office of Justice Programs. https://bjs.ojp.gov/content/pub/pdf/cpffcl09.pdf

Business process workflows: The business process workflow is defined as the means by which evidence flows through the forensic laboratory. Laboratories need to be sure that their LIMS aligns to the workflow or their workflow can accommodate pre-defined settings established by vendors. Changing business processes to conform to a well-established COTS LIMS can be challenging; however, laboratories should consider modifying or redefining workflows to COTS LIMS as it conforms to established workflows set by the vendor. Each laboratory will have to determine if they can implement a COTS LIMS by configuring software options in combination with making changes to their business process workflow.

When implementing a LIMS in a forensic laboratory, the report identifies lessons learned and best practices among experts to broaden an understanding in the selection or upgrade and implementation of LIMS. These insights include:

- Identify key metrics and needs for LIMS reporting capabilities
- Understand the costs required for implementation
- Anticipate and allocate resources for internal or external IT support
- Recognize the requirements to maintain interfacing systems
- Understand opportunities and limitations of "systems-based" communication between stakeholders
- Appreciate agency policies and resources for procurement
- Implement testing, training, and production processes

An overview of commercially available products (as well as approaches to internally developing these systems) provides key factors decision makers must consider prior to implementing the LIMS. Finally, recommended implementation steps and timing offer the roles and responsibilities a laboratory may consider establishing or upgrading a LIMS.

To develop a successful LIMS that meets the needs of all stakeholders, the forensic laboratory must understand all requirements of end users, define the business workflow processes, anticipate and allocate for IT (and other implementation) resources, and identify opportunities and challenges of interfacing systems both within and outside the forensic laboratory.

The role of laboratory information management systems (LIMS) in forensic laboratories

A LIMS is critical in the management of evidence processing in forensics laboratories today. According to data from Project FORESIGHT, a self-evaluation tool used by crime laboratories to understand their key performance metrics, backlogs have risen by 250% across different laboratory disciplines from 2011 to 2017; and average turnaround have increased by 60%.[3] These requests for services cross multiple disciplines within forensic science, and each request may include multiple items of evidence that require different analyses. Large caseloads and increasingly stringent accreditation requirements necessitate the use of technology to ensure that evidence is tracked, assessed, and documented accurately and transparently.

A LIMS is a software-based system that collects, creates, and stores all data related to forensic examinations in a crime laboratory. At the case level, information collected in a LIMS enables the laboratory to easily track the status of an item of evidence. This data can be leveraged to understand key performance metrics, such as individual caseloads and turnaround times for specific laboratory sections, which help leadership make informed decisions about resource management, justify additional funding and resources, and report pertinent information related to performance metrics for a grant or discovery information for a court case. LIMS can be scaled to federal, state, and local laboratory systems of different sizes and organizational structures.

While laboratories may use LIMS in different capacities, all LIMS are information management software products that offer a standard set of basic functions:

- Document case-related information
- Manage laboratory processes and resources
- Enable data integrity and security
- Generate internal and external reports

> "It would be very difficult to manage a laboratory and be successful without the implementation and use of a LIMS. These systems will at a minimum track chain of custody records in an auditable format, manage data for various applications, create laboratory reports, provide documentation of accreditation requirements including technical and administrative reviews, and track activities of employees. Most LIMS go far beyond these capabilities and it is up to the Laboratory to implement the system and develop it to its maximum benefit for the laboratory. This takes resources in both time and personnel to optimize the system to be seamless with laboratory operations."
>
> —Jody Wolf, Crime Laboratory Administrator, Phoenix Police Department Crime Laboratory

As laboratories have adopted LIMS, advanced features have enhanced the functionality and roles of the program in the laboratory. These features include:

- Streamlined communication abilities between agencies, laboratories, and courts
- Data aggregation for comparison, benchmarking, and trend analysis
- Configurability to adapt to changing laboratory and stakeholder demands
- Supplies and consumables management system
- Integration of new software products and technologies into the laboratory

[3] U.S. Department of Justice (DOJ), Office of Justice Programs (OJP) National Institute of Justice (NIJ). (2019). Report to Congress: Needs Assessment of Forensic Laboratories and Medical Examiner/Coroner Offices. https://www.justice.gov/olp/page/file/1228306/download. Backlogs are defined as cases open for more than 30 days at the close of the fiscal year, and turnaround time is defined as the number of days between a request for service and a report issued back to the requesting agency.

Basic LIMS Functions

Documentation of case-related information and chain of custody

A LIMS is effectively a database management system (DBMS) that collects, creates, and stores all data related to forensic examinations in a crime laboratory, from the submission of an item of evidence to reporting results. These data include but are not limited to case information for pieces of evidence, contextual and investigative information from the submitting agency, prescribed analytical methods, analysis preparation procedures, analyst notes, test results, quality control processes, records of evidence storage, retention, and consumption, and any relevant reports generated from the examinations.

In addition to storing evidence and case-related information, LIMS clearly document chain of custody, from the time an item is entered into the system, through analysis, and ultimately, until transfer of evidence back to the submitting agency or court system. All pieces of evidence can be bar-coded, allowing items to be easily searched. As a repository for all data and corresponding reports, LIMS can be used to generate discovery material and associate written procedures with casework, so that relevant case information is easily available to criminal justice stakeholders.

Incorporating a LIMS can help a laboratory achieve and maintain compliance with the accreditation standards (e.g., International Organization for Standardization [ISO] standards, FBI Quality Assurance Standards for DNA) that require laboratories to accurately track and maintain evidence chain of custody throughout the laboratory. Relevant accrediting bodies include the American National Standards Institute (ANSI)-American Society for Quality (ASQ) National Accreditation Board (ANAB) or the American Association for Laboratory Accreditation (A2LA). In addition, LIMS can store important quality assurance (QA) and other documents that are necessary for the laboratory accreditation process. These products enable laboratory managers to easily access information needed for reports, audits, or other requests.

Implementing a LIMS helped the Beaufort County Sheriff's Office centralize data sources. Read more about their use of a LIMS on page 22.

Management of laboratory processes and resources

The ability to effectively manage processes and resources is a major factor in managing cost and capacity in a forensic laboratory. The process of how evidence flows through the crime laboratory is described in this report as the workflow business process. LIMS enable laboratory managers to view the entire crime laboratory's caseload or item load and the turnaround time from receipt to reporting. An accurate estimate of processing time allows laboratory managers to manage the pending casework and prioritize high-priority cases. This ability supports optimal allocation of resources for case analysis. LIMS enable laboratory managers to assign cases based on current resource allocations, helping them balance workloads for analysts and identify and plan for additional resources needed.

LIMS also help laboratories with their QA processes, such as a chain of technical and administrative review processes. LIMS can streamline the peer-review process through an automated request system that automatically sends reports to the next reviewer. This can help ensure that reports go through the necessary quality control measures by providing staff with timely alerts when a case is ready for review.

Enablement of data integrity and security

LIMS documents all interactions with the evidence—who has analyzed the evidence, what updates have been made to the request for service, such as data reviews, interpretations, and conflict resolutions. To maintain valid data, LIMS protects the raw results from alteration after an analysis has been made, documents the analysis, and locks authorized data fields. Laboratories can audit storage locations to keep track of who accessed the evidence and when the evidence was placed into or removed from inventory or placed into storage conditions. LIMS allow laboratories to apply

access restrictions to certain portions of the system depending on operational needs. The result is greater confidence in the quality and accuracy of the data in a court of law, and a reduction in ability to introduce data entry errors.

Generation of internal and external reports

Crime laboratories generate important information in their day-to-day operations. LIMS reporting capabilities enable the lab to aggregate these insights and package relevant information for appropriate stakeholders. These products can create reports regarding specific cases, such as a report of results obtained by analyzing submitted evidence for the requesting agencies. Reports that aggregate data from multiple cases, such as pending case work and metrics to assess how efficiently a laboratory may be running, are often used for reporting performance metrics for grants, or justifying additional funding to leadership.

"Getting meaningful management information out of a LIMS is more difficult than entering the casework data. LIMS solutions will come with "standard" management information and workload reports either built in or as part of the initial configuration package. Producing ad hoc reports or customizing the "standard" reports can be resource intensive. Plan on the need to invest in having the ability (in-house or contract) to develop and modify reports."

—Rick Tontarski, Principal, IntelliForensics, LLC

LIMS simplifies the process of creating and sending these reports, offering pre-set or custom templates for reporting needs within and beyond the laboratory. Laboratories that use LIMS with reporting software such as SAP Crystal Reports can automatically pull the data into pre-set templates, reducing the amount of time needed to create these reports. Laboratories can also generate electronic interim reports to share with the requesting agency prior to the release of the final report. Some LIMS also offer modules that automatically generate reports related to discovery information needed for court proceedings.

Specialized LIMS features

Through its core functions, a LIMS serves as an important tool to securely and efficiently keep track of all evidence coming in and out of the crime laboratory. Commercial providers, which are often closely in tune with the evolving needs of their customers, have developed key value-adding features that can improve the operations of a laboratory.

Streamlined communication abilities between agencies, laboratories, and courts

The 2020 Report to Congress: Needs Assessment of Forensic Laboratories and Medical Examiner/Coroner Offices, defines institutionalization of communication systems between forensic science service providers (FSSPs), customers, and criminal justice community stakeholders as a key need for laboratories. LIMS can provide a means to communicate with these stakeholders. The management of evidence through the criminal justice community requires close engagement. Evidence is usually transferred from a requesting law enforcement agency to a crime laboratory (and then later returned to that agency), and analysis reports are requested by the requesting agency, the judiciary, and other stakeholders. LIMS providers and developers are streamlining this communication by incorporating methods by which stakeholders can easily communicate with forensic laboratories. These include:

- **Pre-logging portals**: Some LIMS use a pre-logging portal function, which allows agencies to input information about the evidence and their requests for service prior to physically delivering the piece of evidence for analysis.
- **Interfacing with other data management systems**: Some LIMS vendors have developed corresponding property and evidence management systems that can be used by requesting agencies to streamline the transfer of information from agency to laboratory. LIMS may also interface with other management systems or databases such as records management systems, property and evidence management systems, and investigative databases that enhance interoperability between criminal justice information sources.

The agencies supported by the Idaho State Police Forensic Services use Porter Lee's web-based portal to pre-log evidence. Learn more about the system on page 31.

Data aggregation for comparison, benchmarking, and trend analysis

While the basic functions of a LIMS include storing and enabling the aggregation and reporting of relevant case data, the software can be used in meaningful ways to gather data that can be used to inform the greater forensic community about important trends. LIMS vendors and research entities are currently exploring ways in which laboratory data can be used to inform and improve laboratory operations. Two key examples of these efforts include:

- Project FORESIGHT, an NIJ-supported performance benchmarking model that helps crime laboratories self-assess and compare their performance metrics with similar laboratories. This project standardizes terminology and provides key insights into efficiencies in casework, personnel, and expenditures. Personalized reports can help laboratories diagnose inefficiencies and resource needs, justify funding requests, and identify required levels of personnel down to the laboratory section. To improve participation in this project, the FORESIGHT team is currently working with the American Society of Crime Laboratory Directors (ASCLD) on its FORESIGHT 20/20 project, engaging with LIMS vendors including JusticeTrax, Porter Lee, and STARLIMS to develop a freeware that can help extract data from multiple computer systems and lower the barrier to submitting data for FORESIGHT.
- The Drug Enforcement Administration (DEA)'s National Forensic Laboratory Information System (NFLIS), collects results of drug chemistry analyses from state, local, and federal laboratories. NFLIS works with LIMS vendors or with the internally developed LIMS of participating laboratories to reduce burden of data reporting. These data help inform DEA of drug trends at the local and national data. Aggregated data are shared with the community through Midyear, Annual, and Special reports.

The FTCoE has disseminated multiple resources about the FORESIGHT project, including:

- Success story describing the value of FORESIGHT data to laboratories, including the experiences of two early adopters.
- Workforce Calculator tool to help a laboratory identify the right number of personnel to support a level of casework within each area of identification
- Overview webinar of FORESIGHT
- Podcast and webinar providing an overview of efforts to understand the effects of the opioid crisis on laboratory resources
- Podcast outlining efforts to understand jurisdictional return on investment for DNA databases
- Journal articles explaining the hidden costs of the opioid crisis and their implications for financial management.

Efforts like these enable laboratories to develop actionable data- such as return on investment, local and national trends (such as commonly detected novel psychoactive substances, or laboratory sections that are seeing higher backlogs than other sections) and justifications for expansion in certain disciplines, that can help laboratory management make informed decisions and improve operations beyond workflow management. Consequently, increased adoption of LIMS by laboratories of all sizes across the country enable projects like FORESIGHT and NFLIS to gather more accurate and helpful data for their studies.

Interfacing of laboratory software and equipment to serve as a centralized resource

LIMS are incorporating more and more functions and becoming comprehensive, "one stop shops" for analysts thanks to the LIMS' relationships with third-party software applications. These vendors typically interface through application programming interfaces (APIs) to bring information from other valuable systems into the LIMS; these systems can include digital evidence management or digital image comparison software. In addition to software interfacing, LIMS can directly interface with laboratory equipment so that data from these instruments directly uploads into the LIMS. This ability enables users to access a variety of tools and information sources directly through the LIMS and reduces time needed to move the data into the LIMS.

The Arizona Department of Public Safety has integrated multiple third-party software providers with their JusticeTrax LIMS to carry out their day-to-day operations. Read more about their case study on page 21.

Configurability to adapt to changing laboratory and stakeholder demands

Because of the nature of the work, the demands on forensic laboratories are constantly changing. Laboratories develop new methods, require new report fields, and integrate new instruments based on technology, policy, and other updates. Some vendors offer a configurable, rather than a customizable, system, which gives appropriate individuals within the laboratory the power to adjust these systems to their needs.

Laboratory supplies and consumables management system

LIMS can help the laboratory easily understand current laboratory inventories, including expiration dates of reagents and their stock other consumables and easily request reorders of supplies. It is important for laboratories to track and maintain their stock of supplies as it can take time to purchase and restock these materials, reducing the possibility of downtime from a lack of consumables needed to perform analyses. Oftentimes, new purchased reagents and standards must be validating prior to use, and proper inventory management will allow the laboratory to account for these necessary procedures prior to existing materials expiring. This system is another way to centralize laboratory information and passively keep track of laboratory operations.

Both basic and advanced features of LIMS provide significant value for forensic laboratories of all sizes and capabilities. However, these systems are not “plug and play”; deriving these benefits requires comprehensive front-end planning to construct a system that meets the needs of the laboratory. The following sections provide an overview of stakeholder needs, approaches to LIMS development, and implementation considerations for developing or upgrading a LIMS in a forensic laboratory.

Planning for LIMS implementation

A LIMS can provide valuable information and workflow capabilities for forensic laboratories. This value, however, is directly influenced by a laboratory’s effort to understand their needs, communicate them to vendors or developers, and collaborate with them to build the program. Laboratories should consider the roles and preferences of the many end users of LIMS and LIMS data, and then build or upgrade their LIMS around a defined business process workflow.

Identifying stakeholders and needs

A successful LIMS addresses the needs of its end users. However, laboratory personnel use LIMS in a variety of different ways (Figure 1) depending upon their role in the organization, and thus, they have different needs and priorities for features of a system. The following discussion provides an overview of key end users, their roles in the laboratory, and their needs and wants for a LIMS, including: Evidence Controllers, the Requesting Agency/Customer, Forensic Examiners, Section/Unit Managers and Technical Leaders, Quality Managers, Chief Information Officers and Senior Leadership/Laboratory Directors. The priority given to each stakeholder’s input is not necessarily tied to their place in the organizational hierarchy. Creating buy-in, super-users and champions requires careful consideration of all personnel needs and wants. LIMS that are designed to make middle managers happy at the expense of bench-level examiners, or to provide the laboratory director with minute operational details while over-burdening section chiefs with data entry, are likely to fail. This section outlines key preferences for LIMS features of different laboratory personnel (and other relevant parties), which are based on the way each player uses the software day-to-day.

Balancing the Needs of LIMS End Users

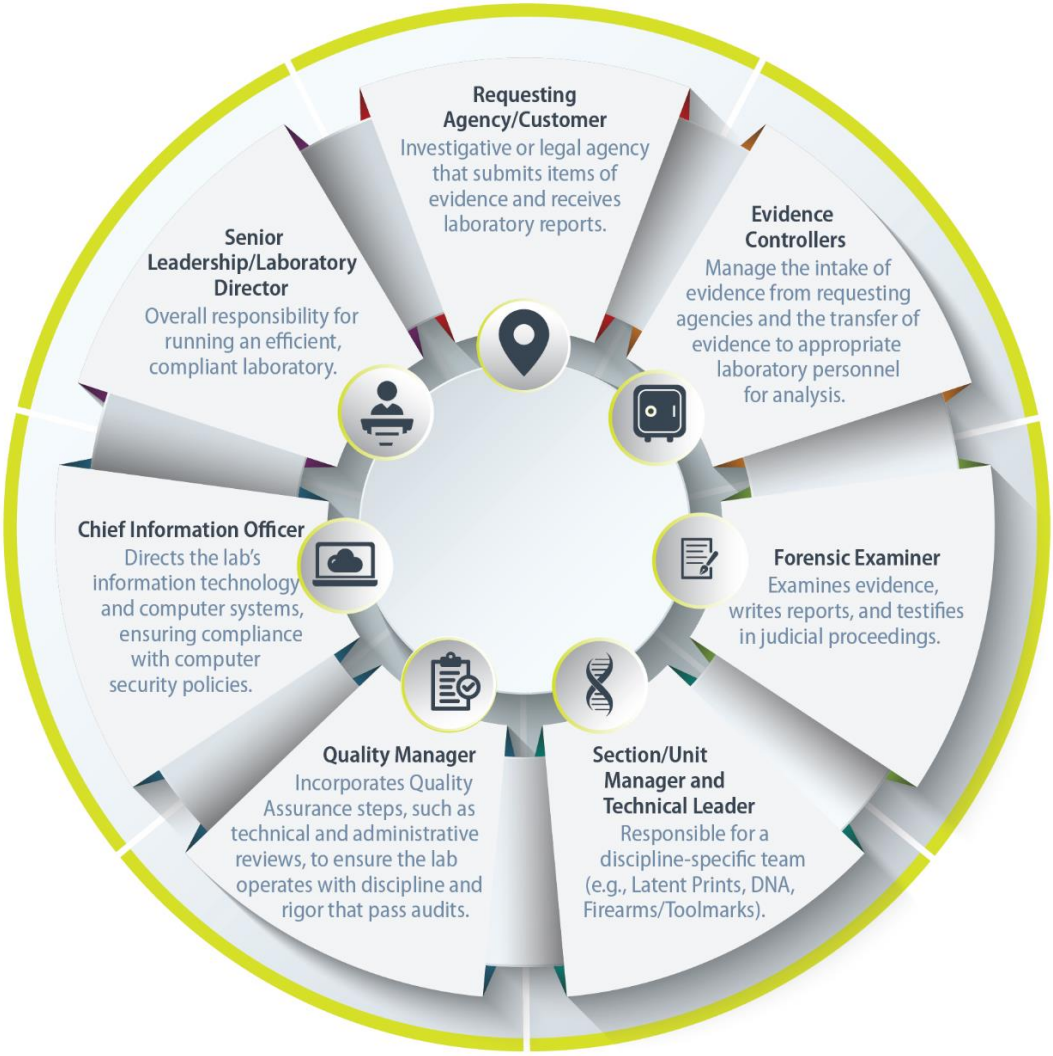

Figure 1: Creating a valuable LIMS requires input from all types of LIMS users inside and outside the laboratory. Decision makers must balance these needs to create a system that provides value for all stakeholders.

Requesting Agency/Customer – This is the investigative or legal agency that submits testing requests for items of evidence and receives laboratory reports.

Typical LIMS Preferences:

- Streamlined laboratory request and submission process that will adopt metadata and previously created information about items of evidence and case details
- Compatibility with their existing databases (e.g., case management)
- Dashboard status of all cases submitted to the laboratory
- Visibility of details about individual cases/items of evidence
- Ability to receive electronic interim reports (e.g., DNA results, latent print results) that may be available before a final report that encompasses a complete analysis of the evidence
- Production of streamlined and automated responses to discovery requests

Evidence Controllers – These individuals manage the intake of evidence from requesting agencies and the transfer of evidence to appropriate laboratory personnel for analysis. Depending on the size and structure of your laboratory, this function could be done by a dedicated intake unit or, in a smaller laboratory, by an individual property manager; in other laboratories, these duties may be distributed across each discipline-specific unit/section.

Typical LIMS preferences:

- Interoperability with existing databases, property and evidence management system (PEMS), and investigative databases that will limit duplication of data entry
- Reliable and robust method for controlling chain of custody
- Flexible options to generate sub-items and route/assign material evidence to units or individuals
- Dashboard view of the disposition of all items and sub-items of evidence

"Involving staff at the earliest stages of LIMS implementation creates staff ownership and buy-in. It also taps their best ideas and creativity to maximize the value of LIMS to improving casework flow and documentation."

—Dr. Ray Wickenheiser, DPS, MBA FAAFS, Director, NYSP Crime Laboratory System

Forensic Examiner – The bench-level scientist who examines evidence, writes reports, and testifies in judicial proceedings.

Typical LIMS Preferences:

- Intuitive and easy to operate user-interface
- Helpful QA and discipline-specific modules that set conditions for success with sequential prompts and required fields
- Flexibility to change workflows when indicated by the contextual information of a given case
- Security and traceability of data entry
- Automatic generation of reports that minimizes duplication of effort and opportunities for administrative mistakes
- Dashboard view of all assigned work and relevant due dates

Section/Unit Manager and Technical Leader – In most laboratories, the mid-level managers and technical leaders have responsibility for a discipline-specific team (e.g., Latent Prints, DNA, Firearms/Toolmarks).

Typical LIMS Preferences:

- Flexible options to manage and change assignments
- Dashboard view of all assigned cases, items, and sub-items of evidence
- Intuitive QA modules that allow cases to easily transition back and forth from technical and administrative reviewers to examiners
- Menus for commonly required workload and case status reports
- Ability to generate configured reports without special IT support

Quality Manager – In a large laboratory, the Quality Manager may be the leader of a dedicated team. In smaller laboratories, an individual may serve as a Quality Manager alongside other roles, such as a Deputy Director.

Typical LIMS Preferences:

- Surveillance and documentation of all entries to allow for thorough QA and, if needed, root-cause analysis
- Workflows that incorporate QA steps, such as technical and administrative reviews
- Compatibility with programs that curate standards and policies (e.g., quality management software programs) to ensure that examiners are only directed to current documents

- Highly prescriptive workflows that prohibit examiners for using "work-arounds" to skip steps in an examination method, process, or procedure
- Ability to data-mine for trends that could indicate systemic weaknesses and opportunities for improvement

Chief Information Officer – This role will depend on the size of the laboratory and the structure of the parent organization. In a small laboratory, these responsibilities may fall to a forensic examiner as a collateral duty. Larger laboratories may have a dedicated section that handles all IT-related issues. Sometimes, the laboratory's parent organization may retain control of IT policy and support.

Typical LIMS preferences:

- Clear and affordable hardware/firmware/software requirements
- Compliance with computer security polices
- Clear and affordable data archiving solution
- Appropriate redundancy to allow for minimal LIMS down-time
- Separate environments (e.g., Production, Testing & Training) to allow upgrades, troubleshooting, and configuration changes to be tested outside of the operational production LIMS

Senior Leadership/Laboratory Director – In a small laboratory, these duties may be the responsibility of a single leader. Larger laboratories may have several individuals serving as assistant directors and in similar roles. In a large, state-wide system involving multiple, geographically separated labs, senior leadership may consist of multiple Laboratory Directors.

Typical LIMS preferences:

- High-level reporting of key laboratory metrics, such as turnaround time/backlogs, for use in annual reports and testimony to legislature
- Honest and realistic proposals with no hidden costs or over-idealized promises about capability during the acquisition process
- Flexibility to makes operational changes to the business process workflow without "breaking" the LIMS
- Quick and easy training requirements for LIMS users
- Menus for commonly required workload and case status reports
- Dashboard view of all activities in the laboratory
- Ability to generate configured reports without special IT support
- Ability to capture Project FORESIGHT workload data
- Ability to incorporate all laboratory activities and collateral duties (e.g., expert testimony and consultation for completed cases, crime scene investigation field support)

Defining business process workflow

The business process workflow describes how evidence flows through the crime laboratory. Crime laboratories need to make sure a LIMS is put in place that facilitates the natural business process and workflow. Trying to change business processes to conform to an application that has already been developed is challenging. This may happen to some degree, but it is up to the laboratory to determine what is feasible and what changes can be tolerated. One vendor's systems may be more accommodating of and more easily adaptable to the established workflow in the laboratory. Understanding the different business operation workflows for each domain can help ensure a good match that meets the needs of the crime laboratory.

"Much like validation of new technology, develop a plan, communicate the plan, train the software and document your successes."

—Kevin Lothridge, Executive Director, National Forensic Science Technology Center at Florida International University (NFSTC@FIU)

Starting or changing a LIMS is much more of a leadership challenge than an information management activity. Adopting a LIMS may be as disruptive and transformative as going through ISO

17025 accreditation and may reveal ambiguities in laboratory policies and expose inconsistencies in team practices. Yet the realized benefits and efficiencies of these adoptions by far compensate for the temporary disruption. Laboratory management play a key role in defining the vision and ensuring that the proper steps have been taken to appropriately plan for and execute a successful LIMS deployment.

The following business process questions are based on insights and lessons learned by crime laboratory directors who have previously implemented a LIMS. These questions are important to work through with all stakeholders, including laboratory leaders and practitioners, before choosing and implementing a LIMS.

- What is a "case/submission/request" at your laboratory? For example, on Monday, a customer submits a dozen items from a crime scene. Then, on Thursday, they submit five more items for a search warrant on the same investigation. Is the above situation one or two "case(s)/submission(s)/request(s)?"
- How does your laboratory calculate a "turn-around-time"? How does your laboratory calculate a "backlog"?
  - When does Day 1 start? Upon receipt of the items? After some holding time.
  - Does your laboratory have criteria for placing an item in a pending status?
  - What is the last closing date for a "case/submission/request?" When the report is issued? When the evidence is returned? After some sort of judicial disposition?
  - Do you track turn-around-time and backlog for specific disciplines?
- Does your lab have a serial workflow (i.e., where items move from one discipline to the next) or a parallel workflow (i.e., where a case management or triage team simultaneously sends swabs to DNA, processed prints to Latent Prints, and firearms to Firearms/Tool Marks? Are you hoping to move from serial to parallel in the future?
- How uniform are the examination processes between and within each section/unit/discipline?
  - Consider a scale with total freedom (i.e., individual examiners decide how to handle each item of evidence) at one extreme and total control (i.e., every individual in every section/unit/discipline follows a tightly controlled checklist) at the other end. Where is your laboratory on this spectrum, and where do you want it to be?
  - Most LIMS can be configured to be more descriptive or more prescriptive. Descriptive systems carefully document the choices examiners make during the examination process. Prescriptive systems direct and control the choices examiners make. Where is your laboratory on this spectrum, and where do you want it to be?
  - Most LIMS have a hierarchy or permissions that identify which roles or individuals are authorized to override required entries, make changes to errant data entries, or change modules. Where and to whom do you want these authorities granted?
- Are you content with the current organization, roles, and responsibilities in your laboratory? Wherever possible, make these changes before transitioning to a new LIMS:
  - Consolidating sections/units/disciplines or adding new ones
  - Promoting or moving key personnel.

"Employees will not like any new LIMS (that's human nature) but the transition can be eased with "local" (unit) champions if they were included and involved in the entire implementation process."

"I wish I had known the benefits, and necessity, of having multiple LIMS "administrators" instead of just one in the laboratory. Multiple people with some level of administration capability whose efforts can be leveraged against each other, not multiple absolute-top-user-role competing admins."

—Adam Becnel, Manager, Louisiana State Police Crime Laboratory

Consulting organizations are available to help a crime laboratory identify and refine their business workflow practices and select and implement the LIMS that best suits their needs. Many bring years of experience that will help the laboratory plan for additional upgrades for equipment while addressing any potential compliance issues. While professional contractors can provide value in facilitating this process at the front end, senior leadership participation is key for appropriate alignment of expectations and ultimately a better end product.

LIMS Product Landscape

Today, most forensic laboratories employ some sort of LIMS. As indicated by the BJS Census for Publicly Funded Forensic Crime Laboratories (CPFFCL), between 2002 and 2009, there was nearly a 10% increase in the use of LIMS, and in 2009 approximately 9 out of 10 publicly funded laboratories employed a LIMS.[4] A recent NFLIS survey sent to 172 state and local crime laboratory drug chemistry sections with a 94% overall survey response rate (162 laboratories) asked laboratories to report the type of LIMS used; of the 143 that answered, 12 laboratories (8.4%) have an internally developed LIMS, and 131 (91.7%) use a COTS. [5,6]

Adopting a LIMS for the first time or transitioning to a different LIMS requires laboratory decision makers to choose between making or buying the system. Each approach to implementing LIMS has unique benefits, challenges and tradeoffs as depicted in **Figure 2** and described in the following sections. In choosing one option over another, it is important to understand the degree of flexibility and robustness that each LIMS offers.

Options include:

(1) **Purchasing a COTS**. Laboratory decision makers must understand the benefits and limitations of COTS and consider the extent to which their business process workflows must align to the vendors' products. COTS may be configured to meet some of these workflows but customizing software code to conform with all business processes may present significant challenges. COTS may therefore be considered more rigid than flexible as in **Figure 2**. Similarly, COTS has been vetted by the vendor and customers alike and represents a robust option for forensic labs. The following sections address these concerns and others and provide summaries of four key product vendors on the market.

(2) Creating an internally developed or "homegrown" system. Laboratories that internally develop their LIMS benefit from full and agile customization abilities to fit the actual business process workflow and accommodate changing needs. However, this requires considerable maintenance and systems must be supported by a knowledgeable and dedicated IT staff member who is assigned to the system. Maintaining and updating to the latest software and validation requirements may be challenging for IT staff. Therefore, internally developed systems are considered more flexible, but may require more active effort to maintain, as referenced in **Figure 2**.

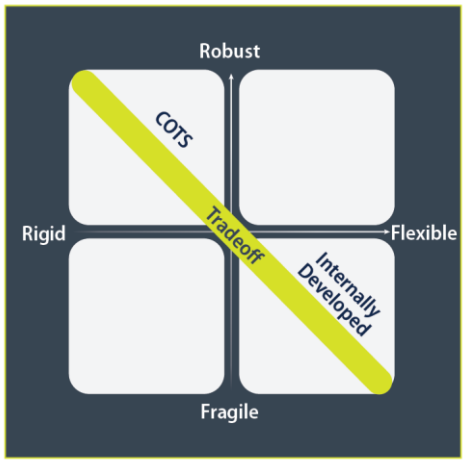

Figure 2: Decision makers must balance flexibility to easily update features with a system that hold up to these changes. COTS and internally developed systems offer benefits and tradeoffs for these key qualities.

Overview of Commercial off-the-shelf (COTS) LIMS

COTS LIMS provide solutions for many crime laboratories looking to implement or upgrade their current system. Many COTS offer value-adding features beyond basic LIMS capabilities, such as modules for specific disciplines, the ability to

[4] Durose, M. R., Walsh, K. A., & Burch, A. M. (2012, August). *Census of Publicly Funded Forensic Crime Laboratories, 2009*. NCJ 238252. U.S. Department of Justice, Office of Justice Programs. https://bjs.ojp.gov/content/pub/pdf/cpffcl09.pdf

[5] U.S. Drug Enforcement Administration, Diversion Control Division. (2019). *NFLIS-Drug 2019 survey of crime laboratory drug chemistry sections report*. Springfield, VA: U.S. Drug Enforcement Administration. https://www.nflis.deadiversion.usdoj.gov/DesktopModules/ReportDownloads/Reports/13121NFLISdrugSurveyRpt6Nov29.pdf

[6] Note that percentages and Lab # based on Table 1 in report. Reports makes note that "percentages may not sum to 100% because of rounding".

interface with property and evidence management systems (PEMS) and other information management systems, and compatibility with third-party software, such as reporting/visualization software or digital content management. Vendors also provide updates to the software that ensure compatibility with operating systems, interoperability, and compliance with changing ANAB requirements.

Table 1 provides an overview of COTS benefits and limitations. COTS LIMS customers benefit from the regular updating, feature adding, and bug fixing efforts offered by the vendor. Many of these updates are borne from user feedback, in opportunities such as annual user meetings where software providers solicit feedback from customers. Such meetings also give users opportunities to network and discuss new features to address challenges. User meetings serve as vehicles to foster ideas from the community that could be implemented in later versions of their software.

> "It is critical to consider how much customization you really want in your LIMS programming. Customization makes routine upgrades and maintenance both expensive and time intensive."
>
> —Matthew Gamette, M.S., C.P.M., Laboratory System Director, Idaho State Police Forensic Services

Challenges with COTS LIMS include their limited ability to adjust to a crime laboratory's current business process workflow. While internally developed systems are built up from the specific needs of the laboratory, COTS are generally modified from existing worksheets and processes to fit into laboratory workflows. While COTS users benefit from the vendor's IT and customer support, their ability to update their systems depends on the availability of the vendor staff, as well as their ability to afford change orders. COTS vendors may be capable of making some adjustments; however, the crime laboratory will be committed to the vendor's overall concepts of workflow. These features may or may not work well with the laboratory's business process workflow.

Table 1: COTS LIMS offer robust and continuous improvement tools but might have limited ability to adjust to a laboratory's specific business process workflow.

COTS LIMS Benefits	COTS LIMS Limitations
• Wide selection of features to enhance the functionality of the LIMS • Compatibility with other information management systems and third-party software • User community and interaction with vendor salesforce influences new features • Updates available to ensure compatibility with operating systems and compliance with changing ANAB requirements • On-call 24/7 customer support available for issues that cannot be easily solved by an IT administrator	• Limited flexibility to customize the LIMS to a crime laboratory's specific workflow process • Deploying and maintaining a COTS system (including change orders necessary) incurs costs that must be anticipated • Crime laboratories may be reluctant or too busy to update their systems to newer versions • Vendor response to updates/additions depends on their availability

Considering COTS LIMS products relative to business process workflows

Many options exist in terms of how laboratories interact with their customers in receiving requests and evidence. These details play an important role in selecting a data structure within the LIMS that works for the laboratory's needs. Although most modern LIMS vendors offer some flexibility in how data are structured, each vendor will have an underlying paradigm for how to handle items, events, and data. By way of simple analogy, a bakery could have a data

structure based on customers or a data structure based on donuts. These two approaches are evidenced in the bakery's end-of-day summary, which might state that the bakery "had 26 customers who purchased 372 donuts" or "sold 372 donuts to 26 customers." Using a spreadsheet as a very primitive DBMS, the fundamental structure is determined by deciding which data will constitute the rows and which will be the columns. In the example above, if the bakery were to use a customer basis, each new customer would get a new row. Although LIMS vendors use much more sophisticated software, most will have one of the following primary data elements: a) a submitted item of evidence, b) request for examination/activity, or c) container of samples received by the laboratory. Finding a COTS vendor with a compatible underlying data structure paradigm will make it easier to successfully implement a LIMS. Laboratories that implement a COTS LIMS may choose to use the program as designed out of the box, or they may alter the program to fit their needs (summarized in **Figure 3**).

Upon purchasing, vendors work closely with the laboratories to set up these programs. COTS LIMS can be changed in two different ways: some features are customizable, meaning that upon request, the vendor can hard-code the changes into the software. Some features are configurable, meaning that the vendor has programmed the software so that the end user can implement changes to the workflow. Each vendor offers some level of customizability and configurability to their software. Each of these approaches have different benefits and limitations. Customizable features are addressed by the vendors' IT teams but may require costly change orders. In addition, a high level of customizability developed in a LIMS up-front can cause challenges when workflows change years down the road. Configurable features enable users to make quick changes as needed but may be difficult to change without an IT background. Laboratories with flexible systems must be careful to limit unnecessary changes that could affect the laboratory's ability to aggregate and report data (for example, if a naming system or categories are changed). **Table 2** provides an overview of the benefits and challenges of these types of features.

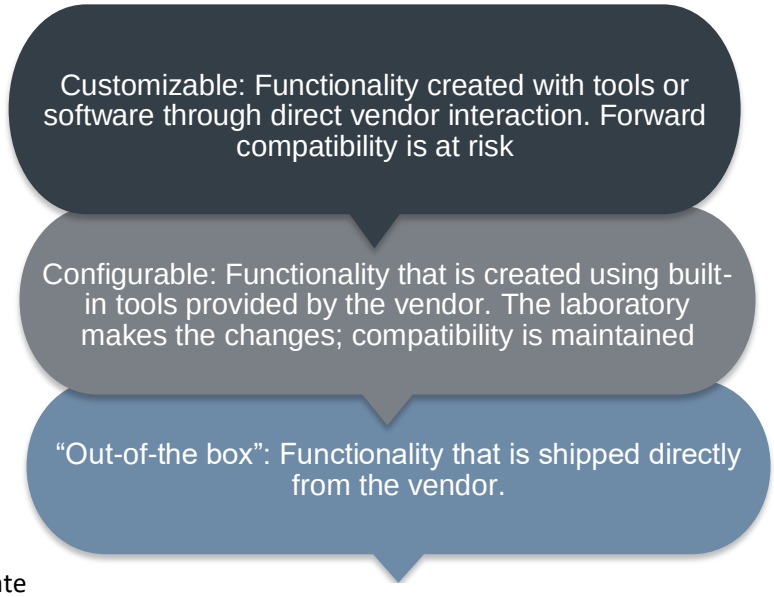

Figure 3: COTS providers offer features that are either customizable or configurable, which describe who can effect changes to the system (i.e., vendor vs end user, respectively). Some COTS vendors provide a rigid "out of the box" offering for smaller laboratories that requires laboratories to work around the system.

Table 2: Customizability and configurability of a system offer varying benefits and challenges for a laboratory.

Customizability		Configurability	
Benefits	Considerations	Benefits	Considerations
• The ability to make LIMS fit in an existing workflow • Ability to make changes quickly without waiting for user-group consensus or development of next COTS version • Limit risk of "breaking" the system	• Customizing may necessitate costly change orders • Systems with a high level of customization may not be able to accommodate updates or deployment of new features • Changes depend on availability of vendor	• Users can make the changes that they need by themselves, on their own time • The hard-coded software does not change • Changes do not cost money	• Frequent changes may impact ability to aggregate and report data • Process of configuring software may not be user friendly • Limited features may be customizable

Laboratory decision makers must understand what is "customizable" and what is "configurable" for each software vendor they are considering. Systems with configurable systems support agility and flexibility over time, whereas systems with customizable features can be limited in their ability to upgrade, change, or add new features. Suppose a business process followed over the last 10 years is to automatically generate a laboratory request when an item is logged. Recently, however, the volume of requests increased to the point that a system change was desired. In systems where this is hard coded as a customizable change, the laboratory will have to contact the vendor that can facilitate changing that code. In systems that have configurable features, the LIMS administrator or other dedicated individual could make this change.

In some circumstances, vendors have developed "out of the box" solutions that require little setup or alteration. These offerings are designed for smaller laboratories that likely are implementing a LIMS for the first time. They are intended to be cost effective and require minimal time to launch; however, it appears that more vendors are turning to general product offerings instead of offering these specialized software products.

The Kansas City Police Crime Laboratory found customizability to be valuable for aligning a LIMS to laboratory processes and needs, but eventually ran into issues as they continually improved their system. Page 32 provides more information on their experience.

Commercially Available LIMS Products

There are many commercially available LIMS, including systems that are built for case management within the medical examiner/coroner community, as well as systems that are built specifically for the workflows of certain disciplines, such as toxicology and DNA analysis. This landscape provides an overview of four commercially available products that develop products for the forensic crime laboratories that provide services across multiple disciplines: Abbott's STARLIMS, Forensic Advantage, JusticeTrax LIMS-plus, and Porter Lee's BEAST. These four products represented a selection of key market players chosen based on interviews with LIMS implementation experts, as well as literature such as publicly available crime laboratory LIMS manuals and the NFLIS-2019 Survey of Crime Lab Drug Chemistry Sections.[7] These vendors services are outlined in the following pages. Please consult the vendors for changes or updates to these features after time of publish.

[7] U.S. Drug Enforcement Administration, Diversion Control Division. (2019). *NFLIS-Drug 2019 survey of crime laboratory drug chemistry sections report*. Springfield, VA: U.S. Drug Enforcement Administration. https://www.nflis.deadiversion.usdoj.gov/DesktopModules/ReportDownloads/Reports/13121NFLISdrugSurveyRpt6Nov29.pdf

Abbott's STARLIMS

Company Overview

STARLIMS Forensics is a paperless system that ensures compliance, reduces costs, minimizes errors, and provides management reports to make informed decisions. Solutions are designed by industry experts and are tailored to meet the distinct forensic lab workflows, regulations, and standards required by the client. This LIMS product has a fully integrated quality management system.

Revenue model

The "on-premise" installation is a perpetual concurrent license (i.e., laboratories can have as many named users as needed). The number of those users that can log in at any given time is controlled by the number of concurrent licenses. There are full concurrent licenses for users who enter data and data concurrent licenses, which are lower in price, for users who need to log in to get status updates and reports. GSA pricing is available. The cloud option uses a subscription. Clients own their data even if they are no longer a subscriber. Maintenance costs vary by package requested.

Client Platforms - STARLIMS offers both on-premises and software-as-a-Service (SaaS) models. For the on-premises option the entire application is hosted on customer's servers. For the SaaS model STARLIMS requires Internet Explorer and Windows Workstations. The STARLIMS Website can also be packaged as a Windows Native App that does not require Internet Explorer.

Interoperability - Due to the large array of possible systems and different client requirements each interface is custom built. The interfaces are normally implemented using Web Services technology. STARLIMS also supports a variety of other options as well including direct file transfers, direct database connections, ActiveX, COM, etc.

Modules – Product modules include: Evidence Pre-Log, Service Requests, Laboratory, Property, Crime Scene, Evidence Reception, Chain of Custody, all forensic disciplines, Quality Management, Equipment Management, Inventory Management, Discovery/FOIAs, and Productivity. STARLIMS can interface with most software services. SAP Crystal Reports is used as the STARLIMS Reporting Engine. Advanced Analytics is used to create dynamic dashboards.

Configurability - The system is configurable. Forensic Workflow Settings is a feature that permits a high level of configuration without writing code. Customers can configure their own static tables, add new analyses, create new reports without coding or vendor services.

Reporting - STARLIMS forensic offering has a robust and flexible approach to examination reports by using Microsoft Word templates. The lab units can have multiple MS Word templates and when generating the report can choose the appropriate one. Complex Examiner Reports can be automatically generated using MSWord Tags. STARLIMS also uses SAP Crystal Reports as a Reporting Tool. This tool allows for quick creation of reports according to Client's specifications. The forensic product permits users to create reports without writing code using its case or property print template tool. Productivity Reports offer a flexible module to permit the creation of statistical calculations and their use in multiple productivity templates.

Software updates - The technology platform is updated two or three times per year and the business (forensic specific) layer is updated every 18 to 24 months on average. Feedback is received by working with new clients, responding to Request for Proposals (RFPs), and seeing industry needs, discussions with existing clients, and feedback during product demonstrations. Laboratories can provide formal feedback through a client support/satisfaction tool, Zendesk.

Forensic Advantage

Company Overview- Forensic Advantage Systems® (FAS) has worked closely with law enforcement agencies toward the design and implementation of numerous mission-critical applications. Designed in cooperation with Microsoft Corporation, Forensic Advantage® was originally designed and developed to address the unique case and evidence management requirements of local, state, and federal forensic laboratories. Since that time, the product has been configured and extended to address the evolving needs of law enforcement agencies, medical examiners, and digital forensic laboratories.

Revenue model - Client payment is based on services requested and delivery model. On-premise installation payment includes project implementation / configuration service, server license and user license. SaaS options include project implementation, per user fees and cloud usage fees beyond standard usage.

Client Platforms - The application and database reside either on-premise or in a client-owned or Forensic Advantage hosted cloud setting. The hosting requirements vary depending on hosting option selected.

Interoperability- Forensic Advantage has integrated with multiple record management systems, property and evidence management systems, and quality management systems that have APIs. In a typical installation historic data is either integrated into Forensic Advantage or stored in the FA object repository for future reference. A documented FAS.API is provided to facilitate programmatic integration with external systems.

Modules- Product modules include: Evidence/Specimen, Case Processing, Resource Manager, Instrument Integration Service, Activity Module, Testimony, Object Repository, Discovery Module, FA Portal, Administration, Property Connect, Firearms, Batch Processing, AuthXAccess, DNA Databank, DUI Breath Alcohol Databank, and Sexual Assault Kit Tracking. The Forensic Advantage platform can store any file type in the object repository and associate those files with a case. Forensic Advantage supports multiple reporting and digital visualization tools (DevEx, DocGen, SSRS, Power BI, Tableau, etc.).

Configurability- The entire platform is highly configurable, allowing the system administrator to manage help text, field names, drop-downs, documentation, report templates, etc. In addition, full access is provided to create custom reports and to extend the application via integration with 3rd-party systems. Much of the system also allows the layout and content of screens to be updated by the System Admin. Where possible, Forensic Advantage tries to avoid customizations that are unique to a single customer. Rather, change requests are implemented as configurable product features so that future upgrades do not cause problems.

Reporting- Nearly 50 out-of-the-box reports are provided with the core system. In addition, DevEx, DocGen and SSRS can be used to modify standard reports or to create new reports. Industry-standard reporting tools are supported so that customers can easily manage their reporting requirements.

Software updates - Software is updated twice-annually and all users are provided with access to new software updates. User and Admin guides are published with each software releases. Each software release is tested internally to confirm COTS integrity and subsequently tested in client stage environment. The customer care site collects and prioritizes feature requests so that product updates address emerging requirements in a timely fashion.

JusticeTrax LIMS-plus

Company Overview - JusticeTrax offers a fully integrated COTS system focused solely on forensic LIMS. LIMS-plus is a case management software tool that integrates evidence tracking, analytical results and lab management information.

Revenue model - JusticeTrax software applications are sold under a Named User License Agreement. The licenses are perpetual and are re-assignable. When a user leaves the customer, their account is deactivated and assigned to the new user. JusticeTrax also provides software maintenance, which provides customer support, upgrades to applications, and access to video-based training in JT Academy.

Client Platforms - JusticeTrax LIMS-plus is a browser-delivered application. LIMS-plus is installed on an agency network server as an on-premises solution. The LIMS-plus application and database reside behind the agency's firewall and is protected by the local Information Technology Support staff, including disaster recovery. Users access LIMS-plus via internet browsers commonly available today. JusticeTrax relies on industry standard Microsoft solutions and architecture, including SQL database.

Interoperability - JusticeTrax has worked with 3rd party vendors to exchange data and images including, but not limited to, record management systems (RMS), digital information management systems (DIMS), and quality management systems (QMS). JusticeTrax has also successfully interfaced LIMS-plus with customer data and systems. LIMS-plus also includes a set of RESTful Application Programming Interfaces (APIs) for added interface capabilities.

Modules - JusticeTrax LIMS-plus is a full-featured LIMS application capable of deploying in any forensic laboratory system. JusticeTrax LIMS-plus includes analytical modules for controlled substance, toxicology, blood alcohol, and firearms. LIMS-plus also includes a "general" analytical module that can be configured for virtually any forensic discipline / service, as well as administrative services. Each of the modules that are included can be configured via the analytical module administration functions where users can configure several default settings for each module.

Configurability - JusticeTrax applications are highly configurable, allowing full language or idiom replacement, granular control of user roles and permissions, and the addition of custom forms (worksheets) and customer fields. All configuration is available for customer execution, with no need to await JusticeTrax availability, and at no added costs. Customization is not provided on a per customer basis. As applications are enhanced, those improvements are rolled into the next version(s) as upgrades for all customers. This single codebase approach allows all customers to upgrade simultaneously.

Reporting - LIMS-plus provides access to statistical/administrative reporting using SAP Crystal Reports to have access to information regarding backlog, work performance/turnaround time, service request monitoring, and much more, to include not only examination but also both technical and administrative review and more. All JusticeTrax-provided data fields and custom fields created by customers are immediately available for query and reporting. Additionally, LIMS-plus includes an ad hoc query tool for added capability.

Software updates - Annual maintenance for JusticeTrax LIMS-plus includes unlimited technical support calls through our accepted communication methods (i.e. Zendesk, Phone or Email), all software patches/updates, and all enhancements to the software and all upgrades to the software. LIMS-plus is normally upgraded one or more times per year.

Porter Lee's BEAST

Company Overview- Porter Lee Corporation (PLC) has provides forensic LIMS and evidence handling software and services. They serve the forensic crime laboratory and law enforcement communities. Their products were born in the crime lab and police property room and are tailored for these environments.

Select Key Features- PLC has developed its next generation LIMS system as an ASP.net, HTML5 compatible, application running under Microsoft IIS. The new application runs under IIS using 64bit instructions. Introduction of the ASP.NET based application allows for web services to be used for interfaces to third party application systems. Interfaces can be implemented using XML, SOAP, ASMX, WCF, or other custom designed protocols.

Revenue model - Payment terms and License types are determined in the contract or proposal phase and include implementation and annual Support. Many methods have been implemented over the years, including Upfront, yearly, quarterly, phased in, etc.

Client Platforms- Porter Lee's application and database reside in the cloud, On-premises, or hybrid configurations are available. They can support cloud (Azure / AWS) or on-premises solutions.

Interoperability- LIMS Interfaces to many off the shelf and custom Records, Evidence, Quality Management Systems. Data can be migrated in, or, connected to in-place. Most any industry standard data source is supported, e.g., ODBC/OLEDB, XML, JSON, WebServices.

Third party software compatible software- SAP Crystal Reports, Microsoft Office (WORD/ Access/Excel), Power BI, Tableau, Mideo, Foray, ImageSafe, etc.

Modules- Full-Service Crime Lab Support for evidence receiving, chain of custody, electronic analysis matrix, report review cycles, and report publishing. Complete Integrated Evidence Management System (EMS) and fully integrated modules for DNA and Toxicology

Configurability -The application includes the ability to add or modify fields on entry panels dynamically without making source code level application changes. In the same manner, columns in data grids can be modified through configuration. This allows new functionality to be added to the application without having to extensively retest the entire application because the source code and application itself has not changed. Custom programming is also available.

Reporting - Stock – Typical listing reports that are case related. Case Reports, Chain of Custody, Inventory, Certificate of Analysis, Analysis tracking. Management – Statistical Reports for section or laboratory management. Includes Backlog, Turnaround Times. LAM – Having to do with Asset Management. (Includes stock, inventory, consumption, calibration, and service reports)

Software updates - Major builds are made available each year and presented at user's group. Minor builds occur more frequently. Customers have the option to update as needed and implementation of new features or changes are not required.

Arizona Department of Public Safety (DPS) uses LIMS to control stakeholder communication, streamline workflows, and integrate software.

Brooke Arnone is the QA Manager and Beth Brady is a Crime Laboratory Manager and LIMS Administrator for the Arizona DPS.

The Arizona DPS was the first laboratory in the state to adopt the JusticeTrax LIMS-plus system around 2000. Eventually, the entire state adopted JusticeTrax as their choice LIMS. DPS serves over 200 agencies as a state laboratory and has three separate property and evidence units used to house evidence to be analyzed. Although DPS is a longtime LIMS-plus user, the department has not yet gone completely paperless: some records for cases are kept as paper copies and include content such as hard copies of chromatograms from analyses and handwritten analyst notes. However, DPS uses its LIMS-plus for the following:

1) **Reporting:** LIMS-plus can monitor the status of not only singular cases but also aggregate data generated from the laboratory to better understand productivity and laboratory management. JusticeTrax software is connected with SAP Crystal Reports, which helps DPS compile data for case-related analysis reports, aggregate reporting for grants and other purposes (i.e., looking at pending case work and efficiencies), and personnel management within the laboratory.
2) **Chain of custody management:** LIMS-plus provides the necessary safeguards for chain of custody management that cannot be as well controlled with paper systems. Electronic chain of custody is also easier to track down remotely compared to paper trails. This is especially helpful to manage evidence tracking through DPS's four different locations.
3) **Communicating within and outside of the laboratory:** LIMS-plus streamlines communication between individuals in the laboratory and enables controlled information dissemination to necessary stakeholders in the criminal justice system.

DPS has found that using LIMS-plus for these critical crime laboratory functions offers the following benefits compared to analog tracking:

- **Easy access control for different stakeholders:** JusticeTrax software offers varying levels of access for end users of the system, which include users within the laboratory (e.g., administrators, directors, analysts) and outside the laboratory (e.g., outside agencies, federal laboratories, prosecutors). Defining user access controls using LIMS-plus helps laboratories safeguard their information and only provide laboratory information to those who have specific needs to know.
- **Workflow efficiency enabling:** The laboratory handles over 39,000 requests per year, and each report must go through an established process of checks through the department to ensure quality. The LIMS ensures that this quality control process happens, tracks the progress of the case, and alerts the right stakeholders when a review is needed. LIMS-plus also helps with effective workflow management: analysts may self-assign requests as they come in or be assigned a batch of cases to work through using the LIMS. This enables a more seamless and efficient workflow of cases, which can contribute to a reduction in pending case work.
- **Interoperability with other types of software programs:** In addition to JusticeTrax's LIMS-plus, the DPS uses a variety of software tools to effectively operate their laboratory. JusticeTrax has developed relationships with vendors such as SAP Crystal, Mideo, and Qualtrax, which enable DPS to perform analyses, create reports, and manage the laboratory. Functions of these products are integrated into LIMS-plus to streamline the analysis process.

Key lessons learned:

- LIMS-plus is not the "end all" for laboratory functions: More software products are necessary for the laboratory to effectively function, and integration with these software products is a key benefit to end users.
- LIMS-plus provides value to laboratories even if they are not entirely paperless.

Beaufort County Sheriff's Office (BCSO) Forensic Service Laboratory understands how to work efficiently under resource constraints.

Lt. Renita Berry is the director of the BCSO Forensic Services Laboratory in South Carolina. Timothy French is a DNA Analyst and LIMS Administrator.

The BCSO Forensic Services Laboratory is a small forensics laboratory in South Carolina with a staff of seven. The BCSO adopted a LIMS around 2009, when the laboratory was implementing its DNA section. The laboratory was one of STARLIMS' first forensic laboratory users, which enabled the laboratory to customize the LIMS to their needs at a price point that worked for a small laboratory. The BCSO originally purchased an "out-of-the-box" system that STARLIMS offered for smaller forensic laboratories, which worked effectively for them as they were building up their own laboratory system from the ground up. However, STARLIMS eventually switched their customers over to their core offering, which provided much more functionality. The BCSO uses LIMS to establish and maintain chain of custody, record results, process and review reports, track communications with customers, track inventories of equipment and reference standards, to produce stats, and to produce invoices and originally adopted a LIMS due to its ability to limit access to specific types of data and clearly record when data has been changed. While their system offers other benefits, such as evidence pre-logging, document control, and instrument interfacing, the team currently does not have the capacity to maintain these functions but hopes to do so within the next six months.

With such a small team, laboratory members must take on multiple roles to ensure that their systems are working smoothly and that the laboratory itself is working efficiently. Besides the inherent security measures of the software, implementing the LIMS has offered the following benefits, which have saved time and improved capacity for the laboratory:

- **Centralized document storage:** Previously, the team used multiple locations for storing information, such as test records and supplier information, on share drives and SharePoint. The LIMS now acts as a centralized system for all information important to laboratory operations. The ability to aggregate information by case number or item number helps the BCSO to easily track down information that they need, saving valuable time. The ability to track inventories of equipment and reference standards is also of great benefit.
- **Time-saving report dissemination:** The reports generated via the laboratory's analyses are stored in the LIMS, must be disseminated back to the requesting agencies, and are frequently requested by other solicitors, such as prosecuting attorneys. The LIMS streamlines the process of sending reports via email to requesting agencies and provides a record of this information transfer in the system. Sending these reports to the requesting agencies enables the agencies, rather than the laboratory, to be the point person for report distribution. This frees up significant time for laboratory staff to perform their main functions.

The team has continued to use STARLIMS through its expansion into the forensics market and purchase by Abbott. BCSO implemented this software when it was very new, and various LIMS features that exist in today's LIMS have yet to be pushed out to the team, including features such as a portal that enables stakeholders (e.g., prosecutors) to view and share information easily. Lt. Berry mentions that post-acquisition, the team has been able to maintain the system for their operations without frequent direct vendor contact; however, the changes and upgrades to the system have been impressive and appreciated.

The team is looking into ways to expand their use of LIMS and evidence tracking; additionally, their main law enforcement agency was, at one point, using STARLIMS for evidence tracking but has now switched to another PEMS. BCSO is looking into ways to interface the agency's PEMS with their STARLIMS to reduce the number of times they need to input the same information into different systems.

Key lessons learned:

- LIMS is not only for managing large laboratories; small laboratories can also benefit from streamlining and efficiency.
- Turnkey systems ("out-of-the-box" option) offer easy setup but are ultimately limited in capabilities and flexibility.

Internally Developed LIMS

Internally developed LIMS are built around the laboratory's specifications. A forensic crime laboratory could approach an internally developed LIMS in multiple ways, depending on their needs. A small laboratory could develop a LIMS using a spreadsheet program (e.g., Microsoft Excel, Google Sheets, Apple Numbers) by using protected fields and macros to create a user interface (**Figure 4**). Larger or more complicated laboratories may need to base their system on a database program (e.g., Microsoft Access, Ninox Database, LibreOffice Base). Still larger and more complex laboratories may opt for a relational database (e.g., MySQL, Oracle, IBM Db2) or an object-oriented program (e.g., ObjectDatabase++, GemStone/S, Wakanda). Each of these approaches requires a different level of effort and cost to build and maintain.

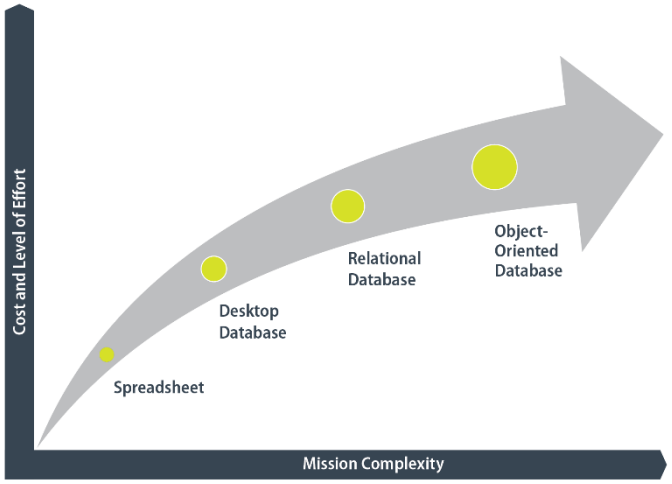

Figure 4. Laboratories may pursue a variety of approaches to internally developing a LIMS, depending on their size, budget and internal technical abilities.

Laboratories that internally develop their LIMS benefit from full and agile customization abilities to fit the actual business process workflows and accommodate changing needs. To benefit from this flexibility, these systems should be supported by a knowledgeable and dedicated IT staff member who is assigned to the system, which may require resources beyond the capacity of police agency IT staff responsible for supporting an entire department. Dedicated IT staff will also provide a smoother transfer of knowledge and ensure that the system is properly maintained and updated with latest software, data encryption, and validation requirements. **Table 4** lists some of the benefits and considerations of internally developed LIMS.

By switching their COTS system for an internally developed LIMS, Orange County Crime Laboratory, California, saved around $10M that would have gone to change orders. Their success was influenced by their ability to fund full-time developers for their LIMS needs. Read more about their internally developed system on page 24.

Table 4: While internally developing a system offers valuable flexibility, the effort requires resources for building and maintaining the LIMS.

Benefits	Considerations
• Full customization to fit actual business workflow processes • Relatively inexpensive compared to COTS offerings • Maximum flexibility to quickly modify business process workflows and required fields	• Must be supported by a knowledgeable and dedicated IT staff member who is assigned to the system • More difficult to maintain and keep updated with the latest software and validation requirements • Recreating a LIMS from the ground up require substantial investments of time and money

Orange County designed a system to maintain the flexibility to adapt to changing technologies and stakeholder needs.

Bruce Houlihan is the Director of the Orange County Crime Laboratory, California.

The Orange County Crime Laboratory in California is a full-service laboratory that serves over 50 agencies in the county. After customizing a commercial mainframe solution in the late 1980-90s, Orange County shifted to an internally developed LIMS, which they have used for almost twenty years. Their current solution is built on industry standard SQL relational databases, with high performance natively compiled front end applications and web sites for the user interfaces and presentation. Orange County shifted away from a COTS system because of the time and expense of customizing the software to the preferences of each discipline. The internally developed system was constructed according to the operations of the laboratory (e.g., the Toxicology and DNA batching systems), rather than retrofitting a standardized system to fit the laboratory. The system exceeds the functionality of off-the-shelf products in terms of evidence tracking, personnel and inventory management, and reporting.

The lab has dedicated IT staff, which has enabled the lab to build a system that can better interoperate with the criminal justice community and stakeholders, and better adapt to their changing needs.

- **Effectively develop an integrated property and evidence management component:** In addition to the laboratory-facing LIMS, Orange County has also developed a web-based portal that enables agencies in the county to manage their own property and evidence, requests for work, reports, and tracking of analyses at the crime laboratory. This streamlines the connection between the agencies and the laboratory and minimizes transposition errors.
- **Quickly integrate new methods into the laboratory:** The Orange County laboratory has connected all of their instruments to the LIMS so that all data are imported and exported automatically. Orange County's IT staff can easily update elements, such as instrument parameters, drug testing methods, and accreditation schemes.
- **Save around $10M in LIMS costs over time**: These alterations cost the department IT labor instead of change orders, which can add up over time and take weeks to complete depending on vendor schedules. While a significant upfront investment was required to develop the database back end, maintenance costs over time have been low.
- **Facilitate communication between criminal justice stakeholders**: At the request of the District Attorney, Orange County built in a triage process on their web-based platform so that the section supervisor, DNA supervisor, investigators, and prosecuting attorneys can determine which evidence can be tested for DNA in property crimes. The LIMS helped these parties communicate effectively and efficiently to manage their resources.

Mr. Houlihan noted that the reporting feature of the LIMS has become especially important for "discoverability." Juries, defense attorneys, and prosecutors are calling for more information on each case, including documents, such as personnel logs, maintenance records, and other case data. In California, prosecuting attorneys can be held personally liable to the defense if they do not release these records to them. The Orange County LIMS can help pull data requested by criminal justice communities quickly and effectively.

> *"Change is constant in forensic science. If your LIMS is slow moving, you're always dragging behind on these changes and your clients will leave you out of the loop."*
>
> —Bruce Houlihan, Laboratory Director, Orange County Crime Laboratory

Key lessons learned:

- Laboratories must have a means to quickly update methods, workflows, report contents, and other laboratory elements to keep up with the demands of the criminal justice community.
- Dedicated IT staff is necessary for the successful implementation and upkeep of internally developed systems.

Implementing LIMS in a Forensic Laboratory

While LIMS can ultimately streamline processes and save time for a laboratory, these systems require planning, resources, and flexibility from both laboratory and system to be successful. Interviews with experts revealed several key lessons learned that laboratories should consider when implementing LIMS, regardless of vendor or internally developed approach:

> "Recognize and accept that your laboratory processes will have to adapt to how the LIMS operates. Leverage what the LIMS does well, and temper your expectations."
>
> —Rick Tontarski, Principal, IntelliForensics, LLC

- Consider key metrics and needs for LIMS reporting capabilities
- Understand the costs for implementing a LIMS
- Anticipate and allocate resources for internal or external IT support
- Consider needs for interfacing software tools
- Understand opportunities and limitations of "systems-based" communication between stakeholders
- Appreciate agency policies and resources for procurement
- Implement testing, training, and production processes

Consider key metrics and needs for LIMS reporting capabilities

LIMS serve two important roles in the laboratory. Clearly, a LIMS plays a key role in the management of current cases. Additionally, such a system also serves as a data archive for previous/closed cases. These data can be used as the basis for all manner of statistical reports on topics ranging from timeliness, to productivity, to costs, to the demand for each type of examination, among others. Furthermore, many laboratories have routine reporting requirements driven by legislative bodies, sponsoring agencies, granting agencies, customers, and stakeholder groups. Laboratories can leverage LIMS to produce useful reports for internal and external stakeholders; however, the quality of these reports is directly related to the measures taken on the front end to ensure that the system is capturing the right information.

> "There are almost limitless amounts of information but there must be a way to mine data and create usable reports. The challenge is that a COTS LIMS rarely has stock management reports that can provide the information that is beyond the routine management interest. The laboratory must have the skill set to query the data and provide it in a usable report."
>
> —Jody Wolf, Crime Laboratory Administrator, Phoenix Police Department Crime Laboratory

The LIMS can only generate reports with data that are routinely collected. For example, a laboratory might have an informal process for conducting technical reviews where Examiner A can ask Examiner B "for a little help with a technical review" without any entry in the LIMS. This laboratory will have no ability to quickly answer questions such as, "How many technical reviews did Examiner B do last month/quarter/year?" When making decisions about how to configure, customize, or internally develop a LIMS, known or desired reporting requirements must be considered. Decision makers must balance inclusion of much information in data fields with keeping the LIMS user-friendly for forensic examiners without excessive data entry, which may cost the examiner a significant amount of time.

Laboratories should understand that generating reports is not an inherent capability of DBMS. Some COTS vendors will offer a menu of pre-defined reports as part of their out-of-the-box capabilities. However, most laboratories will want or need to create more customized reports. Generating these reports will require expertise with other software packages that facilitate extract, transform, and load (ETL) functions. One commonly used product is reporting and data visualization software, such as SAP Crystal Reports. Laboratories can negotiate with their COTS vendor to create on-demand reports, though this option may incur additional expenses. Another approach is to hire or build expertise in the laboratory. For example, a large laboratory might have a LIMS team that includes an ETL expert.

Up-front planning is necessary to define business process workflows and understand how to best set up a system that addresses laboratory needs. While professional contractors can provide value in facilitating this process at the front end, senior leadership participation is key for appropriate alignment of expectations and ultimately a better end product.

Understand the costs for implementing a LIMS

For any agency, implementing a LIMS requires an investment of money, time, and personnel resources over an extended period of time. The extent of this investment depends on multiple factors, including the size and caseload of the agency, the quality of current systems used to store the data, and any changes to the business process workflow. Year One deployment of a LIMS system may cost a laboratory anywhere from around $75,000 to over $300,000 depending on its needs. **Table 5** provides examples of the general implementation and maintenance costs that real laboratories have provided. **Table 6** provides an overview of general cost model information for the four LIMS vendors profiled in the report. Generally, expenses can be categorized in four areas:

Software Licenses: Most LIMS offer a per-concurrent user software licensing model and can have options for yearly or perpetual licenses. Cloud services may require a subscription or data storage costs. While total costs vary on the size of the laboratory, current costs per license tend to run from $1,000 up to $5,000 per license.

Installation and Training: These entail installation, onsite support during implementation and testing, and training costs for administrators and end users of LIMS. This may depend on the size of the organization (for example, a laboratory system with many sites may need more days for training) and the up-front configuration and deployment costs. Depending on the effort required, these costs may be comparable to the license costs.

Periodic Maintenance: Beyond the up-front costs of installing LIMS, vendors charge a yearly fee for updating and year-round support for users. Laboratories interested in upgrading their LIMS to a new version, if they have not kept up with maintenance costs, may require a larger number of on-premise hours.

Other Related Costs: Laboratories should consider the costs of other software products, such as quality management systems and reporting/data visualization software that are necessary for LIMS functions, which may significantly add to the costs. Laboratories should know that other related interfacing software products, such as QualTrax and Crystal Report Software, are separate expenses.

Table 5: Examples of implementation and maintenance costs for a selection of laboratories around the United States.

Jurisdiction Type	Implementation Year	Type of LIMS	Number of Examiners	Implementation Cost	Maintenance Cost/Year
City	2011	COTS	50	$400K	$30K
State	2009	COTS	55	$250K	$30K
State	2006	COTS	238	$275K	Unknown
State	2005	COTS	150	$700K	$55K
City	2004	COTS	152	$150K	$120K
County	2000	Internal	120	$525K	$120K
			Average Cost	**$435K**	**$71K**
			Average Cost per Examiner	**$3,800**	**$600**

Table 6: Pricing models, license costs, and implementation and maintenance costs vary between LIMS providers. While pricing varies by each laboratory's unique situation, this provides an idea of ranges a laboratory may expect. Prices have been rounded for simplicity.

		Abbott STARLIMS		Forensic Advantage	JusticeTrax LIMS-Plus	
Software Pricing Model		• On-Premise Perpetual Full Concurrent Licenses • On-Premise Data Concurrent licenses** • Cloud subscription		• Perpetual (Server + Per User) • Subscription (Per User)	• Perpetual per license cost • Site license for up to 500 users	
Perpetual license costs	Full Concurrent	On-Premise	GSA	Server license: $25,000+ User: $1,500 - $2,500	Base Price	GSA
		$4,700- $8,400 /license	$2,800-$5,00 /license		$3,000-$4,500 /license	$2,900-$4,300 /license
	Data Concurrent	$1,600-$2,800 /license	$1,600-$2,800 /license			
	Designer	$9300 /license				
	Site licensing	N/a	N/a	N/a	$750,000 (up to 500 users)	$716,000 (up to 500 users)
Subscription costs	Cloud Subscription (based on 50 full concurrent licenses)	$29,200 $50/ 250 GB Extra Storage $350/additional Non-Production Servers $700Additional Production Server One time set up fee of $2,500		$80 - $250 per user per month	N/a	N/a
Installation Costs		Training courses, per-diem onsite consultant services, which range from $600- $23,300		Implementation: $50,000+ Hourly Rates: $150 - $175 per hour	Per diem installation services for implementation, installation, configuration/administrator training	
Maintenance Costs		18% of license costs		22% - 24% of license costs	Base Price	GSA
					$540-$810 /license per year	$520-$770 /license per year
Other Costs		Monthly hosting costs; Advanced Analytics, Scientific Data Management System sold separately.		Additional cloud fees charged for excessive data storage levels. Additional modules sold separately.	Modules and accessory software products (CIMS, QMS systems) available for purchase	

*Porter Lee was unable to provide pricing information.

**Data concurrent licenses are for users who consume but do not input data, such as a state attorney's office.

Anticipate and allocate resources for internal or external IT support

> "A robust, well-staffed and well-trained IT department is essential to sustain the infrastructure. In addition, investing in a team of LIMS administrators to support the operational environment is crucial to both examiner staff buy-in and long-term success. Recognize this cost needs to be part of base budget operational costs."
>
> —Rick Tontarski, Principal, IntelliForensics, LLC

While well-developed internal or COTS-built LIMS can be used by all individuals in the forensic laboratory for day-to-day use, maintaining and troubleshooting these systems may require a significant amount of time and IT skill sets from laboratory personnel. While some laboratories may lean on supporting law enforcement agency's IT staff, these individuals manage systems within the entire department and may not have expertise or time to work on a LIMS. It may be challenging to get their attention for projects or daily issues that could potentially shut a crime laboratory down if dedicated in-house support is not available.

Laboratories should consider allocating resources to hire in-house individuals with the skill sets to address LIMS maintenance. If a small issue occurs, a dedicated IT person, such as a database administrator, can quickly diagnose the issue and make modifications. This agility is especially relevant for addressing changes to reporting functions: reporting modules are features that many laboratories use extensively to pull data out of their LIMS, and they can be programmed to produce customized reports. Having dedicated in-house support or choosing software with built-in configurability for multiple features, can help quickly address changes and ensure that the laboratory is keeping up with the needs of its stakeholders. The benefit of having a COTS LIMS is the availability of technical support for more serious issues that cannot be easily solved by an IT administrator. Licenses provide service and support as well as upgrades to the system.

The cost of an in-house IT administrator may be a hurdle for some crime laboratories. However, it is recommended that budgets include this in-house staff member to address small issues and serve as a primary contact for the COTS LIMS provider. Other costs to be mindful of include the servers necessary to store all the data; note that the data generated could be considerable and that expense increases considerably. Storing documentation as images also requires a large amount of space. Plan for terabytes of backup server storage and how much storage will cost in the future. In addition, laboratory directors should anticipate the cost of yearly licensing fees for COTS or custom LIMS – which can be significant.

Consider needs for interfacing software tools

Many commercial LIMS providers enhance the functionality of their product through partnerships with third-party software companies, which streamline the flow of information or capabilities within the LIMS. For example, some crime laboratories use Mideo Systems, which aggregates case-related documents into one place to facilitate tasks such as comparative analysis for latent prints. Captured photographs and examination notes and databases are linked to the LIMS so they can communicate together as part of the business process. Other products include PDF viewers, laboratory instrument software, and quality management systems. While these products ultimately enhance the functionality of LIMS, maintenance of these partnerships requires significant time and resources.

Vendors are constantly updating and addressing bugs through software patches. Consequently, each software product must be updated and tested so that the systems will continue synchronizing with each other. This process takes a significant amount of time (both proactively and reactively), and this time burden can limit the value of integrating the systems.

Anticipating compatibility issues with operating systems is also an important factor to consider. Most systems currently use Windows 10. However, as the operating system reaches its end of life, considerations for new systems must be made. An internally developed system or customized COTS system might be incompatible with a more recent Windows version. As soon as updates or upgrades are released, it is important to test the LIMS against them, even if the laboratory does not plan on implementing the software upgrades. Doing so will enable the laboratory to make changes at a convenient time or as a package to save time and money. Users of COTS LIMS that have out-of-the-box or routine configuration functionality will enjoy the benefits of the vendor testing the systems separately for compatibility and making sure that newer versions are compatible with newer operating systems as they are released.

"The main source of challenges with our LIMS was the limited configuration options of the products. The LIMS solutions are general technology solutions that have some level of configurability, but there are limits to how specific the application can be for any particular agency and or laboratory unit. Additionally, there are limits to how LIMS can be configured for any particular workflow, i.e. the Toxicology workflow is significantly different from the Latent Prints workflow. This has resulted in utilizing additional software applications to improve operations and seek efficiency."

—Jody Wolf, Crime Laboratory Administrator, Phoenix Police Department Crime Lab

Understand opportunities and limitations of creating "systems-based" communication in the criminal justice community

Forensic laboratories are one of many stakeholders who directly handle evidence as it moves through the criminal justice system. In addition to physical transfer of evidence, necessary information about the evidence is transferred between stakeholders as well. **Figure 5** provides an overview of evidence as it moves through the lifecycle of the criminal justice system, and where forensic laboratories play a role.

The coordination of evidence and information through a case necessitates institutionalized communication systems between stakeholders. Effective communication can help investigators prioritize caseloads, help laboratories reduce artificial backlogs, and streamline information dissemination between customers and the judiciary. Forensic Science Service Providers, law enforcement agencies, and courts are examples of stakeholders that employ enabling technologies to manage evidence as it travels in and out of their purview. These information systems are databases that share similar roles as LIMS. Ideally, these software products should include access by other criminal justice stakeholders, or "talk" to other products in what is known as a "systems-based" approach.

A key need outlined in the Report to Congress: NIJ's Needs Assessment of Forensic Laboratories and Medical Examiners/Coroners is enhanced communication between the courts and laboratories so that the status of criminal cases may be updated. As of 2014, 31% of surveyed publicly funded forensic laboratories' LIMS track criminal case status. Lack of communication of this status could lead to unnecessary testing, which may cause an artificial backlog of cases in the laboratory.

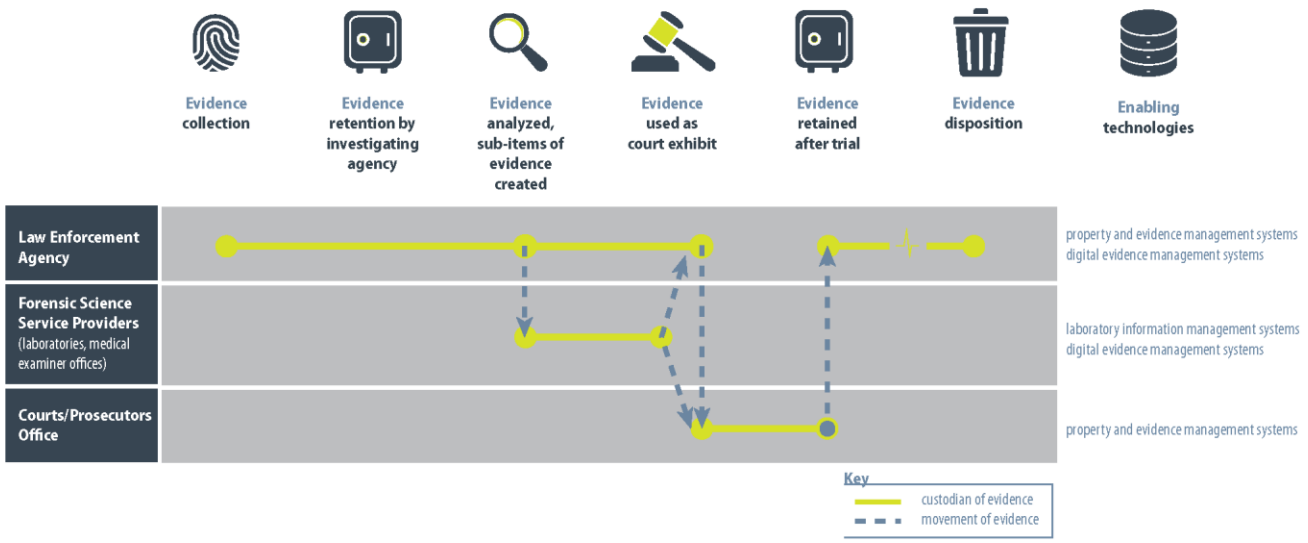

Figure 5: The laboratory represents one of the stakeholders that must manage evidence through the criminal justice process. While law enforcement typically serves as the primary custodians for the evidence, requesting agencies physically transfer the evidence to the laboratory for analysis. While in their purview, laboratory must maintain chain of custody, and can use LIMS to achieve this goal. While this graphic describes the physical flow of evidence, information about the evidence is exchanged back and forth with these stakeholders as well.

Some LIMS can communicate with the criminal justice community through multiple avenues: for example, some vendors and developers build web-based portals for customers to "pre-log" evidence and for customers and the judiciary to request reports and other information from the laboratory. LIMS may connect to sexual assault kit (SAK) inventory, tracking, and reporting systems to ensure all stakeholders, including victims, have access to SAK testing status. Software modules such as STACSDNA help labs meet testing and notification deadlines, improve transparency and accountability, reduce errors, and better manage workloads. LIMS vendors may create a PEMS, which helps manage evidence in law enforcement agencies; requesting agencies with corresponding PEMS software may be able to set up automatic information transfer from the PEMS to the laboratory's LIMS.

While interoperability with other criminal justice systems streamlines communication between parties and minimizes the risk of transposition errors during data entry, establishing and maintaining these systems is resource intensive and difficult to achieve. Information sharing between criminal justice institutions requires compliance with standards for secure transfer of information, which specifies elements such as the type of access available, data encryption, the retention period, the retention time, and other factors related to storage and backups. Systems can be interfaced if both vendors agree to this partnership, and this may incur additional costs.

For laboratories that serve a handful of agencies, coordinating LIMS and PEMS for automatic data transfer could save time in the long run; but for laboratories that support a large number of agencies, interfacing these systems could be resource-prohibitive, and not all agencies may choose to use these software products. In this case, the pre-logging function may make more sense to employ.

"Listen to the recommendations of your LIMS provider on new installs or major upgrades, they are the best position to know how to most efficiently have the process unfold. LIMS vendors install new LIMS more than you do and want it to go as smoothly as possible."

—Adam Becnel, Manager, Louisiana State Police Crime Laboratory

Idaho State Police (ISP) Forensic Services use value-adding portals and integration capabilities; these LIMS features often require continuous maintenance by the laboratory.

Matthew Gamette is the Director of Forensic Services, Britany Wylie is the LIMS Administrator and Forensic Scientist, and Jeremy Johnston is a Forensic Scientist for the Idaho State Police Forensic Services.

The ISP Forensic Services is an accredited, full-service forensic laboratory system with around 50 full-time employees. The ISP has been using a Porter Lee LIMS since 2013 and has integrated multiple types of software products into their system, such as software for breath alcohol instruments, and Foray, a digital evidence management tool for their latent print work. In 2012, the ISP sought out the best vendor for their needs through developing a needs assessment, which evolved into a Request for Proposal (RFP) disseminated to LIMS vendors. The laboratory has shared this RFP with other laboratories looking to implement new systems, such as Puerto Rico's laboratory.

Switching from an internally developed system, ISP team members appreciate the ability of the software program to aggregate data for reporting purposes and projects, such as Project FORESIGHT and NFLIS-Drug. With Porter Lee, the team has been able to implement advanced LIMS functions that streamline communication between stakeholders. One of the most impressive systems they have developed is the pre-logging system through Porter Lee. This system enables their supporting agencies to pre-log and track the evidence they submit. This has the following benefits:

- **Time savings:** Through the pre-logging process, agencies must answer preliminary questions that provide useful context for the laboratory, which verifies the questions upon analysis. Pre-logging also relieves the need for laboratories to re-log the evidence from agencies, which saves time and reduces the likelihood of introducing transposition errors.
- **Continuous stakeholder communication:** The web-based portal enables submitting agencies to keep track of the evidence as it travels through the laboratory. The agency can easily receive, download, and share the reports and case notes they receive, much faster than through "snail mail."

The team adopted Porter Lee software when it was a relatively new to the web-based customer platform. ISP and Porter Lee worked together to develop customized features that helped ISP and other Porter Lee customers. Post-release, Porter Lee is developing more functionalities and features that are difficult to implement in their customized LIMS. However, in the next 6 months, the ISP is moving from their customized model to a "master branch model," a more configurable model with additional value-adding features. The team is looking forward to additional features, especially for data entry screens and reports, as well as enhanced browser compatibility in the master branch version.

> "The value of moving to this master branch system is significant cost savings that stem from agility of configuration. The technology changes constantly, which puts demands on our LIMS. The fees we would have to pay to accommodate these changes- such as a change from Microsoft Internet Explorer 10 to Edge, could set us back tens of thousands of dollars, plus time and effort reprogramming these systems."
>
> —Matthew Gamette, Director of Forensic Services, ISP Forensic Services

While the ISP appreciates their LIMS's capability to integrate with third-party applications, such as the Microsoft Office Suite, they notice a tradeoff in the time spent maintaining these connections. These software products are constantly updated, just as the LIMS. When new versions or security patches are pushed out to these applications, they may break features in the LIMS that utilize these third-party software applications.

Key lessons learned:

- RFPs are effective methods to identify how well LIMS vendor offerings align with laboratory needs.
- Customizable systems provide value up-front to developing a high quality and forward-thinking LIMS, but ultimately may be expensive to maintain and limit adoption of new and improved software features

The Kansas City Police Crime Laboratory understands potential drawbacks of customizability, which may ultimately limit the laboratory's ability to benefit from continuous improvement of vendor-based systems.

Jennifer Howard is the Supervisor of Biology and the LIMS Administrator for the Kansas City Police Crime Laboratory in Kansas City, Missouri.

The Kansas City Police Crime Laboratory (KCPCL) is a full-service regional laboratory comprising around 75 employees, including a crime scene unit. While the laboratory primarily serves the agencies of the Kansas City Police Department (KCPD), it supports around 200 agencies in total. This laboratory was one of the first customers of Forensic Advantage and worked closely with the company to develop their worksheets from a blank sheet. This provided the team an opportunity to look critically at their workflows and design a system that works for their needs. The laboratory has been using Forensic Advantage since 2010 and chose the vendor for its assistance in transitioning data to the new system, and for its easy-to-use interface, which resembles an Outlook application.

When transitioning over to this system, the laboratory made its operations paperless. Their LIMS is integrated with their instruments, such as their gas chromatography-mass spectrometry (GCMS) instruments, where test results are placed directly into case records. The laboratory also has set up an object repository module in its LIMS, where electronic files such as PDF, txt, and email files are stored and can be attached to specific case notes. This system enables all related case data to be uploaded and accessible in one place. Howard notes that an electronic LIMS system allows for use of the data for management purposes to help the KCPCL run their lab more effectively. Statistics like turn-around time, backlogs, productivity, and types of work performed are all tracked without additional input from the examiners. The team used to track these metrics on a Microsoft Excel spreadsheet, and this LIMS feature has saved time previously spent duplicating entries into two different systems. The KCPD appreciates that Forensic Advantage pushes out updates that respond to customer needs. For example, the vendor recently pushed a feature to allow for the review groups so that a technical review could be given to multiple people at one time instead of selecting each person individually. Efficiencies like this are often included in updates from Forensic Advantage and make a difference in the overall efficiency of the laboratory.

Howard explains that the system used by KCPD has more customizability than configurability; that is, most changes are made by the vendor. Customization requires additional funds and lead time to accomplish. Typically, in paper-based systems, a change in laboratory processes costs only the time required to update staff and the paper-based forms. When using a paperless LIMS that is not configurable, the laboratory must pay the vendor an additional fee to make any changes on their behalf. In addition, the changes must be made on the vendor's schedule, and the vendor may have a backlog or requests by other forensic laboratories.

> "Customization can make your LIMS look exactly how you want it. But then ten year later, if you're not doing things exactly the same, you may have to commit quite a bit of resources to redo the system."
>
> --Jennifer Howard, Supervisor of Biology and LIMS Administrator, Kansas City Police Crime Laboratory

With both customizable and configurable LIMS, Howard emphasizes the importance of front-end planning to intentionally develop robust worksheets that align with the laboratory's workflows. This discussion must include end users of the system, like the individuals outlined in **Figure 1**. Howard notes an interaction with a fellow crime laboratory whose LIMS did not meet the needs of their analysts because they were not involved in discussions about setting up the worksheets. While some systems are easier to implement than others, LIMS are inherently not "plug and play" systems: stakeholder discussions and other planning work are necessary to develop a LIMS that suits a laboratory's needs.

Key Lessons Learned:

- To reap the maximum value from a LIMS, the appropriate stakeholders—including end users—need to be involved in planning and implementation discussions.
- Customizable software provides value but can be difficult and expensive to change.

Understand agency policies and resources for procurement

Almost all federal, state and county agencies require their organizations to follow procurement policies when acquiring goods and services above given monetary thresholds. Due to the expensive and complex nature of LIMS, laboratories will almost certainly need to generate a request for proposals (RFP), which allows them to communicate their needs and compare vendor offerings in a standardized way. These RFPs provide insight into what the laboratory values in their LIMS and are often publicly available for reference. For example, the St. Louis County Police Crime Laboratory published their 2013 RFP for a LIMS. However, the required activities and documentation in many procurement policies can lead to a long acquisition life cycle and create delays with implementation of a LIMS.

For implementing or developing a new LIMS, laboratories should consider resources such as DOJ funding for support. Laboratories should consider applying to grant programs such as the Paul Coverdell Forensic Science Improvement Grants Program, now administered by the Bureau of Justice Assistance, which aims to improve delivery of forensic science and medical examiner/coroner services. In 2018, St. Louis County Police Crime Laboratory in Missouri received a Coverdell award (2018-CD-BX-0068) to help purchase licensing for JusticeTrax LIMS-plus for the crime scene unit, so that they may better integrate with the main laboratory. In 2019, the Richland County Sheriff's Department in South Carolina was awarded a Coverdell award (2019-CD-BX-0064) to implement a LIMS to decrease backlogs and turnaround times. Laboratories have also used resources such as the DNA Capability Enhancement and Backlog Reduction (CEBR) Program to implement LIMS in their DNA laboratory, like the Regional Forensic Science Center in Wichita, Kansas (2019-DN-BX-0075).

Implement Testing, Training, and Production Systems

LIMS are continually updating, upgrading, and changing. To effectively roll out changes, laboratories should consider using separate testing, training, and production systems. A test system allows adjustments, modifications, or vendor updates to a crime laboratory's LIMS to be tested off-line. In this way, a crime laboratory can test the LIMS in a safe environment to ensure that an upgrade will not cause a significant issue in the laboratory's operation. A training system allows a laboratory to educate new users on new or upgraded LIMS processes off-line. Laboratories need to consider how staff will be trained on the new software system. Key questions to ask are as follows:

1. How do you roll software programs out? Do you shut down for a week or two, or a period of time so that individuals may be adequately trained prior to launch?
2. How do you manage laboratory operations during this roll-out process?
3. Can the laboratory appoint "super users" in the group who can train the different team members?

If budgets are tight, the training and test systems may be the same. However, such a combined system may slow down development as new features are tested and implemented in the test system that cause new challenges. Training should also be conducted as close to the system live date as possible. This way, the new processes will be fresh in the minds of users and will not be as easily forgotten. Changes to the test system and insights from the training system should be incorporated into the "live" production system.

Developing user-acceptance criteria is another important concept for acquiring, implementing, and updating a LIMS. One approach is to create an artificial case that involves several items of evidence (to include derived evidence like DNA swabs created in the laboratory),and examinations from several disciplines (e.g., latent print, DNA, and drug chemistry, etc.). This case can be used to determine if a new LIMS is ready for operational use and to verify that an existing LIMS is functioning properly after software upgrades. This user-acceptance test case should include not only the examiner interface and data entry but also the production of reports, both pending and completed, to demonstrate that the data are properly captured and included in the metrics.

Implementation Steps and Timing

Choosing and acquiring a LIMS that appears to best meet the needs of the crime laboratory is a significant first step. However, it is important to remember that implementing the new LIMS is a complex and lengthy process (**Figure 6**). It is tempting, but inaccurate, to think that implementing a new LIMS is like upgrading your inventory of laptop computers from Windows 8 to Windows 10. Implementation is not a single activity; it is an expansive campaign that will takes 3-12 months to accomplish. It is important to keep in mind that implementation is fundamentally a leadership responsibility, not merely an IT project.

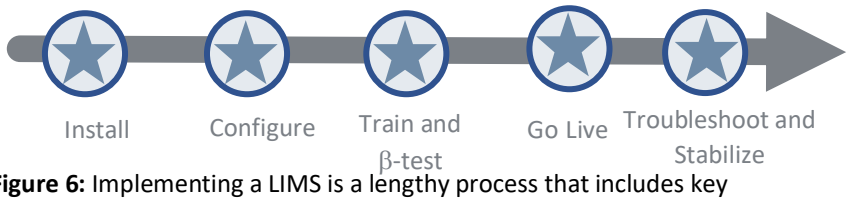

Figure 6: Implementing a LIMS is a lengthy process that includes key milestones to achieve for successful launch.

Except in the rare case of the opening of a brand-new laboratory, the first step of upgrading or implementing a new LIMS is to decide what to do with data that constitute the "old" LIMS. Transferring the old data into the new system may seem trivial. However, the type of data, level of detail, workflows, and data structures used by each LIMS will likely be different. None of these features are standardized by some ISO guidance. In fact, many vendors market these differences to show why their product is better than the competitors'. Trying to force old data into a new LIMS could prove costly and, ultimately, unsuccessful.

The following timeline (**Figure 7**) shows how a medium/large laboratory might implement a LIMS with the following stakeholders: LIMS Administrator or Tiger Team, β-Test Unit(s), all laboratory personnel, IT Team, COTS vendor/internally developed LIMS creator, submitting agencies/customers, and leadership.

There are several roles that are key to a laboratories successful transition to a LIMS. Depending on the size of a laboratory, these roles might be performed by an individual (probably the LIMS Administrator). In a larger laboratory, this team might be led by the Deputy Director and have members with expertise in database management, computer security, quality management & accreditation, examiner workflows, contracting and communication with vendors, training, and project management. This individual will manage the Tiger Team and lead the LIMS transition allowing other personnel to stay focused on the daily mission of completing cases, responding to crime scenes, and testifying.

Establishing teams with specific responsibilities can help streamline the implementation of LIMS:

Tiger Team: The team or individual that is responsible for the transition to a new LIMS. The LIMS administrator role is a very important but not the only role on this team.

β-Test Unit: A unit/section/forensic discipline that is used to pilot the LIMS program before it is adopted by the entire laboratory. This Beta-Test Team can also test significant changes and updates before they are employed laboratory-wide.

Many laboratories will have the capability to designate a unit/section/forensic discipline to pilot the LIMS program before it is adopted by the entire laboratory. A good Beta-Test Unit will:

- Include an established leader who can embrace change and mitigate challenges
- Maintain a caseload and/or workload that has fewer dependencies with other units/sections/forensic science disciplines in the laboratory (i.e., more single-discipline cases)
- Include examiners with good computer/software literacy
- Focus on the LIMS transition for a time (i.e., a team that just launched a big initiative to change their workflow, reduce a backlog, etc., is not an ideal candidate for the Beta-Test Team role)

The Beta-Test team can continue to pilot major upgrades and changes to the LIMS system. This team can also serve as a cadre of super-users to assist with the laboratory-wide adoption of the LIMS.

Finally, it is important to communicate the level of effort required for this campaign to all stakeholders (e.g., forensic examiners, customers, parent organization leadership, legislative funding agencies). LIMS implementation is likely to require increased resources, such as overtime pay, temporary hires, and contract support.

The last step of successful LIMS implementation is beginning to plan for the next LIMS implementation. The simplest consideration is to determine how often to make significant changes to the LIMS. For example, for a COTS LIMS, the vendor may release periodic updates. For instance, a crime laboratory may have purchased and implemented version 4.0, but 9 months later, the vendor releases version 4.1; another 6 months later, they release version 4.2; a year later, they release a major revision with version 5.0; about 6 months later, they release version 5.1 to fix the bugs found in 5.0. In this notional (but fairly realistic) scenario, a crime laboratory could choose to implement every new version. Another strategy would be to stay with version 4.0 for several years and then upgrade to version 5.1. A more extreme consideration is to grapple with the question, "When should a crime laboratory seek a new LIMS?" The criteria needed to answer this question include the following: a) user and maintenance costs, b) level of satisfaction with a COTS vendor, c) changing mission or workflow, and d) disruptive innovations (RFID, Bluetooth, new operating systems, etc.) in the larger computer science community. These criteria will vary between laboratories, but the need to establish and understand these criteria is universal.

"A complete data conversion (complete and absolute usability of existing data in a new system) is a mythical beast. There is no existing system that can be hammered into a different one without loss and compromise of some information. Entertain the possibility of letting an old system sunset at a certain point, or creating a conversion that archives existing data with purposeful loss of some capability or features. Manage to that end rather than thinking you will be able to manage a complete, full conversion only to realize you are stuck with some loss of capability."

—Adam Becnel, Manager, Louisiana State Police Crime Laboratory

	Week 1	Week 2	Week 3	Week 4-5	Week 6-8	Week 8-12
Tiger Team	Lead Functionality Tests	Lead Configuration	Lead β-Team Training	Oversee β-Test Lead Lab-wide Training Lead Daily Hotwash	Lead Daily Hotwash	Biweekly Hotwash
β-Test Unit(s)			Training Operational Continuity	Launch β-Test with Casework Daily Hotwash	★ Deploy Super-Users to other Units	
All Lab				Training	★ Deploy LIMS	
IT Team	Install LIMS Program	Troubleshoot Configuration Establish Training/ Testing Environment	★ Deploy & Support Training Hardware	Troubleshoot Implement Hot-wash changes	Troubleshoot Implement Daily Hotwash	
COTS Vendor/ Homegrown Creator	Onsite/Online support & troubleshoot	Troubleshoot	Support/ Provide Training	Support/ Provide Training Daily Hotwash	Daily Hotwash	
Submitting Agencies			Identify Early Adopter for Online Submission	Early Adopter Training		
Laboratory Leadership	LIMS Kickoff Party and Q&A Session		Vision & Mission Presentations to Open/Close Training	Daily Hotwash	Daily Hotwash	

Figure 7: Implementing LIMS requires engagement from multiple stakeholders within the laboratory, who each have different responsibilities. This graphic provides a sample timeline of LIMS implementation for a medium/large laboratory. This process requires a significant amount of planning and testing along deployment milestones (shown by the blue stars). This graphic explores the tasks that each stakeholder needs to partake in during the initial deployment and implementation stage (weeks 1-12).

	Month 3-6	Month 6-12	Year 2-3
Tiger Team	Lead Weekly Configuration Control Meetings Create Test Cases and Litmus Test Reports that Demonstrate Stability & Functionality of the LIMS	Lead monthly Configuration Control Meetings Downsize, Institutionalize, and Consolidate with IT, QA, Sr Leadership	Plan for Major Version Update (i.e., 2.6 to 3.0)
β-Test Unit(s)		Develop Enhanced Modules for Workflow/ Data Capture/Report Generation/etc	
All Lab	Commit to LIMS use (i.e., no cases worked "outside" the system)		
IT Team	On-going Support for Software Updates and Hardware Replacement	Contingency Failure Exercise – Infrastructure, Hardware, Intrusion Monitor Storage Requirements for Growth, Archive, etc	Establish Replacement Cycle for Hardware, Firmware, Peripherals, etc.
COTS Vendor/ Homegrown Creator	Plan/Advertise CoI – New Version Meetings		Host Yearly CoI New Version Input
Submitting Agencies	Work towards full participation and compatibility with existing systems		
Laboratory Leadership	Enforce Weekly Configuration Control and Resolve Gaps & Seams	Enforce Monthly Configuration Control Commit to LIMS-generated Reports for all Metrics	Participate with Professional Organizations and Publications to Share Lessons-Learned & Best Practices

Figure 7 (continued): Implementing LIMS requires engagement from multiple stakeholders within the laboratory, who each have different responsibilities. This graphic explores the tasks that each stakeholder needs to partake in during the continuous improvement/post-implementation stage (months 3-36 and beyond).

Conclusion

In a forensic laboratory, the value of a LIMS goes beyond an information repository. A well-developed LIMS can play a major role in streamlining workflows, improving communication within the laboratory, identifying actionable insights, facilitating interaction between criminal justice stakeholders, and ensuring that evidence is properly managed and analyzed. Laboratories looking to update or implement a LIMS can achieve these goals through pursuing COTS systems designed for forensic laboratories or can build these systems on their own. Results from this landscape study revealed:

- Adopting a LIMS may be as disruptive and transformative process and may reveal ambiguities in laboratory policies and expose inconsistencies in team practices. Before implementing LIMS, laboratories must understand there is a significant amount of front-end planning and time necessary to design the software to its needs.

- LIMS implementation requires a significant amount of time and resources: deployment can take weeks to months, and setup costs can average around $4,000 per examiner and an additional $600/year for maintenance. No vendor offers a truly "turnkey" solution- regardless of what vendor or approach chosen, they require a considerable amount of up-front work to "build" these products to fit the needs of the laboratory.

- Different stakeholders within (and external to) the laboratory use LIMS in different ways and have unique preferences and needs for a LIMS system. Laboratory leadership should listen to and balance needs of these stakeholders when building the LIMS.

- Most crime laboratories pursue a COTS LIMS offering, and benefit from the platform's continuous improvement, customer service, and built in compatibility with other software products. Internally developed systems, while challenging to build and maintain, offer maximum flexibility to suit a laboratory's changing needs.

- While the addition of interfacing software tools and systems streamline processes and improve communication between stakeholders, maintaining these connections can be resource prohibitive. For example, coordinating LIMS and PEMS for automatic data transfer could save time in the long run, but information flow between these systems may be interrupted when either systems are updated. Agencies should consider approaches to improved systems-based communication through a variety of means, including functions such as pre-logging, which do not require application programming interfaces.

- Crime laboratories that currently use a COTS LIMS are helpful resources for understanding key considerations for implementing the right system for your needs.

Every laboratory has unique business processes and needs. This study's insights are based on the experiences of several crime laboratory directors, LIMS administrators, IT professionals and forensic analysts who have gone through the process of upgrading or implementing these systems.

Resources

Glossary of Commonly Used Words and Phrases

For the purposes of this document, the following terms are defined:

Business Process Workflow: the flow of evidence throughout a crime laboratory.

Beta-Test Team: A unit/section/forensic discipline that is used to pilot the LIMS program before it is adopted by the entire laboratory. This Beta-Test Team can also test significant changes and updates before they are employed laboratory-wide.

Chain of Custody: documentation of evidence from receipt to disposition.

Database Management System (DBMS): a broad term for software that can store and manage information; LIMS is a specific example of a DBMS.

Hotwash: an immediate discussion and evaluation of a group's performance following an exercise or event.

Items: evidence submitted to the laboratory; items are sometimes referred to as exhibits, samples, or simply evidence.

Laboratory Information Management System (LIMS): software used by laboratories to assist with managing laboratory operations: commercial off-the-shelf (COTS) LIMS and internally developed LIMS.

> **COTS LIMS:** refers to a product purchased from a vendor.
>
> **Internally Developed LIMS:** sometimes called a "homegrown" system; these are systems developed by lab personnel or at the agency level.

LIMS Configuration: the ability to rename or create new fields as part of a COTS software application; typically, COTS LIMS have some built-in configurations.

LIMS Customization: changes in the source code of a COTS LIMS implemented by an onsite programmer.

Out of the Box Solutions: LIMS provided by a vendor that does not require laboratory alteration.

Tiger Team: The team or individual that is responsible for the transition to a new LIMS. The LIMS administrator role is a very important but not the only role on this team.

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