Resource Guide

Forensic Technology
CENTER OF EXCELLENCE
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Laboratory Information Management Systems in Forensic Science Service Provider Laboratories: Current State and Next Generation

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Introduction

Laboratory Management Information Systems (LIMS) are computer-based systems that help manage and organize laboratory data, documentation, and processes. They are used in a variety of settings, including medical, research, industrial, and forensic science laboratories. LIMS assist with tasks such as evidence tracking, sample tracking, data management, and compliance reporting. In this guidance document, the authors share the desired and necessary functional requirements of a modern LIMS in a forensic science service provider (FSSP) laboratory with LIMS stakeholders and users. This document will help those seeking to determine the appropriate specifications and checklists for functional requirements necessary for adoption by FSSP laboratories.

One of the main benefits of LIMS is the ability to automate and streamline laboratory processes. For example, LIMS can be used to track cases, evidence items, and samples as they move through a laboratory from receipt to analysis to final disposition. This allows laboratory staff to locate samples easily, track their progress, and ensure they are managed correctly. LIMS can also be used to manage data like test results and assist with compliance reporting, such as generating reports for regulatory bodies, officers of the court, customers, or other stakeholders. In this context, “customers” include any individual or agency that receives a service or report from the FSSP, whereas “other stakeholders” may include legislators, regulatory bodies, and other interested parties.

Another benefit of LIMS is the ability to share data and collaborate with other laboratories, oversight bodies, customers, and stakeholders. Many LIMS have built-in features that allow for data sharing and collaboration, such as web-based portals or secure file transfer protocols. This can be especially useful for multi-site laboratories or integration with law enforcement entities. LIMS can assist with quality control and quality assurance. Many LIMS have built-in features for data validation, such as range checking or data entry rules, which can help ensure that data are accurate and complete. Additionally, LIMS can be used to track and manage quality control samples or proficiency testing samples, which can assist with maintaining laboratory accreditation.

Despite the many benefits of LIMS, there are also some potential challenges to consider, including the cost and complexity of implementing a LIMS. Depending on the size and complexity of the laboratory, implementing LIMS can be a significant undertaking and can require hiring additional technical and information technology (IT) staff or purchasing additional hardware or software. Yearly expenses beyond the initial purchase price include annual service contracts and expenses for laboratory-specific modifications or enhancements. Finally, there is the need to invest in staff training. Because LIMS can be complex systems, laboratories may need to train both new and existing IT staff on how to use, maintain, and update the system properly.

Overall, LIMS are an essential tool for managing and organizing laboratory data and processes. They can assist with tasks such as tracking samples, managing data, and completing compliance reporting and can help with data sharing and collaboration. Stakeholders should consider implementation costs, maintenance costs, complexity, and time to implement LIMS and the need to train staff before deciding whether to implement LIMS.

Several industries have written specific guides for similar management systems, including for prosecutors[1] and law enforcement.[2] Additionally, the Forensic Technology Center of Excellence (FTCOE) published a landscape study of LIMS[3] in 2020. However, this guidance document will outline existing system features and recommended future features that can enhance the next generation of LIMS for FSSP application.

Scope

The authors provide FSSP decision-makers with a comprehensive list of functional requirements to assist with discovering and enumerating functional requirements, both when developing purchasing requirements and creating documents after procuring a new LIMS. Furthermore, this list could be useful to LIMS developers to assess and possibly incorporate the features discussed here into their products. In addition to compiling a list of functional requirements for a modern LIMS (Figure 1), the authors have forecasted what functional requirements may be necessary for a next generation LIMS (Figure 2). A detailed list of functional requirements is accessible as a Microsoft Excel file downloadable on the FTCOE website.

1. SEARCH. (2018, September). *Prosecutor case management system functional requirements.* The National Consortium for Justice Information and Statistics, National District Attorney's Association. https://ndaa.org/wp-content/uploads/PCMS-Functional-Specifications.pdf
2. Joint RMS Standardization Task Force. (2021, April). *Standard functional specifications for law enforcement records management systems: Version III.* IJIS Institute, International Association of Chiefs of Police. https://www.theiacp.org/sites/default/files/2021-06/Standard%20Functional%20Specifications%20for%20Law%20Enforcement%20RMS%20Version%20III.pdf
3. Bollinger, K., Salyards, J., Satcher, R., & Shute, R. (2020). *A landscape study of laboratory information management systems (LIMS) for forensic crime laboratories.* Research Triangle Park, NC: Forensic Technology Center of Excellence, RTI International.

Figure 1: List of functional requirements needed for today's LIMS.

Overview of Functional Requirements for a LIMS

Global Requirements:
minimum viable capabilities needed for LIMS that address FSSP needs.

- **System Requirements:**
features that LIMS should possess to enable secure data storage; limit contextual biases; track relevant data; and enable seamless search across other data systems.
- **System Administration:**
specific features that enable an administrator to effectively manage the data, users, and workflow.
- **Key Equipment/System Capabilities:**
the hardware and software capabilities needed to support effective implementation and LIMS operation.

Workflow Requirements:
features that enable technical FSSPs to conduct tasks for a specific case.

- **Evidence Handling and Chain of Custody:**
features that FSSPs need to track and manage physical evidence from evidence submission to its presentation in court.
- **Evidence Submission:**
features needed to initiate laboratory workflows when evidence is received by a forensic laboratory.
- **Evidence Sign-in and Review:**
features needed to organize and assign tasks after evidence arrives at the laboratory.
- **Evidence Examination:**
features needed to document and review results from examination of evidence.
- **Sample Processing:**
features that enable batch sample processing.
- **Case Management:**
features that help technical staff manage case data.
- **Quality Assurance and Quality Control:**
features that help FSSPs manage reagents, standards, instruments, and QA/QC activities.
- **Analytical Report Development, Review, and Approval:**
features that enable development, evaluation, and authorization of analytical reports that involve the findings of evidence examination.
- **Data Sharing:**
features needed to interface with external information sharing systems and criminal justice of evidence examination.

Management Requirements:
features that enable high-level FSSP management using LIMS.

- **Tracking Module for Training:**
features that enable development and tracking of a structured training program for technical FSSP staff.
- **Management Reporting:**
features that help aggregate and analyze high-level case data to support operational needs and reporting requirements.
- **Budget Metrics:**
features that provide cost analysis capabilities for the FSSP.

Figure 2: **List of enhancements that could be potentially transformative in the next generation of LIMS.**

Developing the Next-Generation LIMS (NG-LIMS)

Global Enhancements:
high-level improvements that impact both day-to-day workflows and management tasks.

- **User Experience:**
designing NG-LIMS to be intuitive and user-friendly, ensuring that users can navigate and operate the system with ease.
- **LIMS Accessibility:**
ensuring the NG-LIMS is usable by the widest range of operators possible.
- **Integration of Human Factors:**
enabling LIMS users to execute tasks considering human elements in NG-LIMS, such as cognitive biases and decision-making processes.
- **LIMS Architecture:**
developing a LIMS architecture that adheres to the principles of being Findable, Accessible, Interoperable, and Reusable (FAIR).
- **Data Standards and Best Practices for LIMS:**
establishing guidelines and protocols for data management within LIMS to ensure accuracy, reliability, and consistency of the data handled by NG-LIMS.

Workflow Enhancements:
improvements to help technical staff execute day-to-day tasks.

- **Process Optimization:**
automating repetitive tasks, streamlining workflows, and reducing the manual workload on laboratory personnel.
- **Digital Object Management:**
ensuring integrity and accessibility of digital objects through improved organization, storage, and retrieval.
- **Operational Performance:**
facilitating the processing of cases, management of workflows, and the adaptability of the system to meet the changing needs of the laboratory.

Management Enhancements:
improvements enabling high-level management of cases and tasks.

- **Exchange Protocols:**
streamlining how different computer systems share information.
- **Prioritization Controls:**
allowing users to manage the priority of different tasks and cases.
- **Analytics and Performance:**
developing features to understand high-level case and performance data, and tailor the LIMS interface, including knowledge graphing, system customization, and performance optimization.

CURRENT STATE OF LIMS

The applicability and efficacy of LIMS for FSSPs is well-documented.[3] In a 21st century forensic laboratory, an LIMS is an invaluable tool; however, the spectrum of case management tools among FSSPs currently ranges from manual record keeping to fully integrated electronic systems that handle everything: documenting chain of custody, analyzing data, writing reports, documenting quality control (QC), and ordering laboratory supplies.

Some laboratories use databases to document chain of custody. These laboratories often use resources such as Microsoft Excel or Microsoft Access to facilitate relatively simple databasing functions. Other laboratories use considerably more interoperable database management systems that manage and query all data and records related to forensic cases. More interoperable LIMS not only track the chain of custody from laboratory entry to exit but manage and query case metadata such as evidence description, item description, subject information, and investigative information. Moreover, robust interoperable LIMS equipped with application program interfaces (APIs) manage analytical methods, instrumental data, batched sample matrices, analyst notes, test results, QC processes, and reports of examinations among many other salient aspects of a forensic case record.

Of the many challenges faced by FSSPs pursuing LIMS procurement, the primary concerns are assessing necessary functionality; avoiding customization; managing financial appropriation and time expenditure for development, training, and deployment; and supporting the ongoing costs of an LIMS. These actual and opportunity costs must be weighed. LIMS customization can be costly and time consuming. Customizations that would prevent periodic software updates or those that would require a substantial change in the LIMS architecture to accommodate an FSSP's procedures should be evaluated to determine whether the cost associated with the customization is appropriate compared to adjusting the laboratory processes.

Because of the relatively high cost and inflexibility of older commercial off-the-shelf (COTS) products, many laboratories have historically chosen to develop LIMS themselves. Advantages of internally developed LIMS include the ability to customize the LIMS to how the laboratory operates and to modify or add additional features quickly as the laboratory's needs change. However, the opportunity costs of internally developed LIMS include limited features or limited interoperability with other products. Laboratories that internally develop their own systems should maintain employees who understand the initial programming and are able to shift to new programming languages and databases as technology changes. The advantage of COTS LIMS products is that these systems come with many features, and the operational costs are clear. However, laboratories usually must modify their processes to conform with how the LIMS operates and must wait for the LIMS vendor's revision process when they need additional features.[4]

Laboratories confounded by these choices and constrained by budgets have produced a spectrum of LIMS that incorporate varying features and abilities. At the front end of LIMS implementation, FSSP decision-makers must consider implementing features that support their needs while balancing budgets. However, there is a limited market for forensic-focused LIMS products and vendors may be hesitant to develop features and advancements specifically for forensics end users.

List Limitations

The lists provided are not intended to be exhaustive. Moreover, the authors understand that budget constraints will limit the number of functional requirements some laboratories can incorporate into their LIMS. Consequently, the authors acknowledge that the quality of a laboratory's management system should not be determined by the number of functional requirements that can be incorporated in the laboratory's LIMS. FLN-TWG currently is not aware of an available COTS LIMS system that can meet all the functional requirements outlined.

4. Project FORESIGHT data collection from FY2006 through the present includes annual collection of LIMS detail (COTS or home-grown) from submitting laboratories. Although nearly 90% of laboratories acknowledge using an LIMS, the home-grown versions vary widely in terms of complexity and value. Most of these home-grown LIMS are limited to Microsoft Excel. Note that only two of the 55 ASCLD Maximus awards for efficiency have been earned by laboratories with home-grown LIMS. Although forensic laboratory cost effectiveness is highly correlated with the use of a COTS LIMS, causality has not been examined. We do not know whether the use of a COTS LIMS leads to cost effectiveness or whether it is cost-effective laboratories that choose to use a COTS LIMS.

Functional Requirements

FSSPs play a critical role in providing scientific evidence in legal cases. With the vast amount of data generated by these laboratories, a robust LIMS is essential to manage and track samples, results, and reports efficiently. The remainder of this guidance document describes the desired functional requirements that a forensic LIMS should be able to perform. This section outlines the overall functional requirements of an LIMS that meets a modern FSSP's needs and complies with accreditation standards for maintaining a chain of custody record; implementing security measures; and enabling search and query functions, role-restricted access, user interface functions, crime code tracking, and APIs. These requirements ensure that the LIMS is capable of efficiently managing and tracking the vast amount of data generated by FSSPs.

System Requirements

System requirements include features that LIMS should possess to enable secure data storage; limit contextual biases; track relevant data; and enable seamless search across other data systems.

Data Integrity

Authenticates data integrity by a secure audit trail. Audit trail functionality captures laboratory activities with a date and time stamp along with other details, such as the user ID or name.

Chain of Custody Tracking

Maintains chain of custody records that document the transfer of each item of evidence from collection to laboratory submission to final disposition. The record includes the person or location receiving the evidence and any subsequent transfers. Subdivided evidence is also tracked through a documented chain of custody record. Secure and auditable date and time stamps for transactions are essential.

Security Measures

Implements security measures in compliance with federal guidelines as stated in the Criminal Justice Information Services (CJIS) Division Security Policy to ensure secure data transmission, processing, and storage. The system can use multi-factor authentication to prevent unauthorized access or amendments to data. The system records login data to allow for querying or reporting of the information. These auditing reports are a secondary risk mitigation measure.

Search and Query Functions

Enables records to be searchable and export attributes into reports. It provides ad hoc queries for all entered data and creates exportable reports for entered data. The system can also calculate metrics.

Role-Restricted Access

Assigns role-restricted access to selected pages, actions/functions, case, and requests. For example, an internal investigation case may require highly limited access.

User Interface Functions

Allows for "undo" functions on pages to account for accidental user interface errors and can push notifications to users and create/maintain different logs (e.g., issue log, court testimony, training).

Crime Code Tracking

Tracks crime codes per case, including Jurisdictional, Uniform Crime Reporting (UCR), and National Incident-Based Reporting System (NIBRS) codes.

Sequential Unmasking

Enables sequential unmasking, which is the process of gradually revealing information to avoid contextual biases that may occur during the forensic practitioner's observations and decisions.

Application Programming Interfaces

Enables different applications to communicate with each other. Application programming interfaces (APIs) allow data transfers between systems to happen automatically, saving labor and preventing potential transcription errors. LIMS provides internal and external APIs to key record information throughout the workflow. Ideally, the LIMS vendor will provide APIs for other software to work with the LIMS and the LIMS will be able to work with APIs of other vendors. APIs should provide a method for integrating other software programs, customizing features, and data input screens to a LIMS without altering the base code of the LIMS.

System Administration

LIMS provide secure and reliable access to authorized personnel while being flexible enough to adapt to evolving requirements. LIMS allow for data fields to be changed over time with the ability to extend, increase, or modify such fields as needed. With these system administration requirements, FSSPs can manage evidence and case-related information effectively and efficiently. This section outlines the system administration requirements for a FSSP LIMS, including user management, data fields and tables, barcode labels, user profiles, a workflow designer, access and permissions, and case number changes.

User Management

Provides the ability to create, disable, and set permissions for each active user individually or as part of any defined user group. Designated users will have control over this functionality and the ability to set permissions.

The LIMS can modify the user profile for each unique user, including name, title, and unit changes. All user profile changes go into effect immediately upon entry and are not retroactively applied to past system entries or documents. All changes are maintained and searchable for management reporting purposes.

Data Fields and User-Defined Tables

Provides the ability to extend, increase, or modify additional data fields to create and maintain all data fields stored in or used by the system. The LIMS creates, modifies, and maintains unlimited user-defined tables for pre-populated data field value selection. The data fields can be changed over time, including adding or disabling options. When data fields are updated, the changes go into effect immediately upon entry and are not retroactively applied to past data entries or documents. Older data fields remain intact and accessible.

Barcode Labels

Provides the ability for designated personnel to create barcode labels. These barcode labels can function as a user, unit, and device to support various business functions within the LIMS. Functionalities include user barcode for evidence chain of custody and transfer, processing the chain of custody transfer, physical custody location barcode for a chain of custody and transfer, and other uses such as lot numbers, quality assurance designation, and instrument calibrations. Use of bar codes may be linked with a requirement to input a passcode or pin number to satisfy two-factor authentication requirements.

Active Directory Integration

Grants access to an existing agency active directory in the LIMS for all internal and external users. The LIMS grants needed access based on the agency's active directory. This ensures that user access to the LIMS is consistent with other agency systems.

Workflow Designer

Allows access to a workflow designer to create and edit workflows when necessary. These workflows will make processing evidence consistent and accurate as it proceeds through the different stages of laboratory analysis.

Access and Permissions

Provides the ability to assign access permissions. This role should assign permissions to individuals or groups to allow access to various LIMS functions. The LIMS should provide the ability to set the access, permissions, and functionality of users or groups of users.

Case Number Changes

Provides the ability to change the police agency case number after submission if the case number was provided incorrectly.

Key Equipment and System Capability

This section discusses the hardware and software capabilities needed to support effective implementation and LIMS operation.

Equipment Requirements

Compatibility with non-proprietary industry standard 1D and 2D barcode scanning and current barcode scanning and barcode printing equipment, such as Zebra barcode printers, barcode scanners, and various document scanners. The LIMS allows barcode scanners to read any size and type (1D, 2D) of the barcode without changing set-up parameters. The system also allows users to create 1D and 2D barcodes of different sizes and to print those different sizes without changing set-up parameters. Additionally, the LIMS supports already established custody locations and corresponding 1D/2D barcodes. The system also allows for external barcodes to be scanned for data entry, such as commercial delivery tracking numbers. The LIMS provides the ability for the expansion of future technologies and workflows.

System Capability Requirements

IT Environment. Manages laboratory information from various equipment/software platforms in a flexible fashion, including mobile devices. Flexibility is sufficient to allow for future changes in reagents methods, equipment, and third-party software upgrades performed by the end-user. The software allows for the import and export of standard text files (e.g., .txt, .csv, and .pdf)

The LIMS works in multiple IT environments (e.g., operating system and browser agnostic, virtual desktop, remote access, and networked onsite), provides links to network locations storing case-related data (e.g., images, instrument data files) if such data are stored outside of the LIMS itself, and provides features to convert electronic files in a protected fashion into a PDF. The LIMS also has the ability to combine multiple documents into one.

Data Management and Migration. Can archive the database per federal, state, and local records retention periods and migrate databases to the next LIMS system without extensive programming or data migration fees. As programming languages, database software, and server systems change, the data should remain accessible and useable.

User Notifications. Provides the user the ability to turn notifications on or off for each user for assignments via a dashboard/tab within the LIMS or through email via permissions set by the LIMS administrator or designee. For example, the LIMS sends notifications to the assigned analyst(s) when a new name is added to a case for active assignments and approved reports, but this notification can be turned off.

Dashboards. Provides an integrated tool to create and display multiple internal dashboards. End-users can configure internal dashboards to display user-defined metrics (e.g., unit pending, priority assignments, due dates, turnaround time, backlogs). Additionally, the LIMS provides the ability for the LIMS administrator or designee to assign permissions to create, modify, save, and access internal dashboards to individuals or groups. Internal and web-based dashboards should display real-time metrics when accessed.

Case Records. Allows for simultaneous use by multiple users. The LIMS allows for each unit or section of the laboratory to be able to use all features of the system for their own purposes without negating others' ability to use the same features (e.g., if a worksheet is being used one way by unit A the same worksheet can be used by unit B in a different way). The LIMS provides the ability for multiple users to be in the same case at the same time and for multiple users to save data in the LIMS at the same time. The LIMS provides multiple, laboratory-defined case categories (e.g., status, location received) and the ability to filter or search for items in a case by item designation, keyword, and item type. The LIMS allows for LIMS screens/textboxes/areas to be resized if needed to see all relevant information. The LIMS organizes all case information for efficient entry, review, and retrieval of information. The LIMS provides a way to record and track cases that use grant funding.

Allows for the option to view name types, such as suspect, victim, elimination, database hit, or demographic information as chosen by the unit. The view can be changed with permissions set by the LIMS administrator or designee.

Provides reciprocity when linking cases: if a case number is linked in one case record, the linked case is automatically added to the other record. Linked cases include the reason for the linkage (i.e., CODIS hit, law enforcement link); all linkages and reasonings are in searchable fields. The LIMS provides the ability to upload a document to multiple cases at one time.

Assigns, reassigns, or delete tasks (defined as a specific procedure or assay). The LIMS allows the user to select the procedure option for each assay and provides the ability to access these procedures. An example of accessing these procedures is via a hyperlink to a document management system.

Creates notes and communication logs for a case that has not yet been submitted to the laboratory (no case number exists yet). Once the case is submitted, these notes can become associated with that case.

Case Designations. Assigns a unique case number to each new case in sequential order automatically. The case number generator should be flexible to allow agency configuration. The LIMS auto-creates sequential unique identifiers for each item created and allow for sub-designations. A sub-designation means if there is additional evidence added later, an FSSP may choose to differentiate this case with a sub-designation. For example, case 1001a is a sub-designation of case 1001, where the lowercase "a" is the sub-designation.

Case Communications. Provides a repository for case-related communications. The repository automatically records each entry, including the user who adds the entry and a date- and timestamp of creation. Users can denote the type of entry (defined by the laboratory), have an area for free text, and can attach emails/documents. After saving, the LIMS has security permissions that allow the laboratory to define who can edit and view communications.

Legal Notifications. Provides a user with the ability to denote any legal holds or notes for a case, and the LIMS' "legal identifier" is obvious and visible to any user viewing the case. The LIMS also provides a function that allows each business unit to manage a list of its standard legal discovery documents. When a legal discovery request is initially entered and a user requests a set of discovery documents, the LIMS uses the pre-defined lists to compile the documents for all business units that have approved assignments for the case automatically. The LIMS notifies any user performing work on a "discovery request" case if the LIMS has already compiled discovery documents for the case. The LIMS also allows a user to request an additional set of documents. The LIMS provides the ability to denote whether cases have court dates and can alert users working on a case of the impending due date. Users can add, delete, or modify information pertaining to court requests and court appearances.

Evidence Handling and Chain of Custody

This section describes the requirements for handling evidence and tracking the chain of custody of submitted evidence.

Chain of Custody

The LIMS has the ability to transfer custody of one or more items at one time and will allow transfers to be made manually as a list within the LIMS software or using scanning equipment with printed barcodes or radio frequency identification (RFID).

The LIMS chain of custody records the following data for each transaction:

- Date and time of transfer
- Location/user who received the transfer
- User who made the transfer
- Date /time the custody was received or released
- How the transfer was made (manual/scanned)

All information should be queried, and all chain of custody events are editable based on user permissions.

Allows evidence custody transactions to or from evidence storage locations when the individual initiating the transaction has permission to access the evidence storage location. Permissions to access specific storage locations are provided by the LIMS administrator or designee for users.

The LIMS allows person-to-person evidence transactions only when the person receiving the evidence initiates the evidence transfer within the system.

The user should be able to request specific items and have an email or notification automatically sent to make the request. The notification includes the user requesting, case number, item number, item custody location at time of request, and other custom information defined by the FSSP.

Chain of custody should be independent from the analysis workflow. For example, when an analyst has completed their examination of the physical evidence but has not finished their analysis or report, they should be able to transfer the evidence without impacting the completion status of their reports or other analyses in LIMS. If the examiner subsequently needs to reexamine the evidence, the transfer of the evidence back to an examiner should not affect the completion status of other analyses or open a new case in the LIMS.

The LIMS should be able to handle casework when no evidence has been submitted to the laboratory, and therefore there will not be a chain of custody. For example, the LIMS should be able to manage casework assignments where the analyst examines items in a remote location that cannot be sent to the laboratory. The LIMS should also be able to manage casework assignments where no evidence was examined, but an analysis was performed. For example, when analysts are tasked to participate in a search warrant to collect information that will be used to perform a subsequent analysis that does not require examining evidence. These non-evidence casework activities often include the generation of reports and other documentation that are subject to discovery.

Workflow

Provides the ability to assign an order of priority either automatically or manually to analysis assignments for evidence that requires analyses within multiple analysis units. The system generates a warning to the user at the time of evidence request if an item(s) is being requested out of the specified order. The order of priority can be overridden with permissions set by the LIMS administrator or designee.

Notifications

Provides the following notifications in relation multi-unit analysis of evidence:

- Sends a notification or alert to the user upon assignment of a case with evidence requiring multiple unit analyses.
- Displays an alert displayed when a user tries to take custody of evidence outside of the predetermined order of analysis for multi-unit evidence.
- Notifies the next assigned analyst or supervisor based upon the predetermined order of analysis at completion of analysis. This notification is automated and has the ability to be sent manually.

Custom Queries and Reporting

Provides the ability to query custody reports by various factors, such as storage location, status, user, and case. The results of the query are printable as a report.

Generates a chain of custody document for all or specified items; this report is configurable and editable by the LIMS administrator or designee.

Evidence Submission

This section deals with how evidence is received at a laboratory. It covers data and records that may need to be entered and the functionality required to initiate the laboratory workflows.

Accepts or rejects evidence submissions based on the laboratory's evidence submission guidelines.

Data Entry

Supports unique custom data fields that the laboratory specifies for their agency's customers. Some common information includes the following: voucher, date prepared, invoicing/assigned officer, department/command, charge, lab unit, evidence source, receiving location, receiving date, submitting agency case number, submitted by, number of packages, package description, notes, evidence item information, items, quantity, description, external package label, and currency/denomination.

Some evidence submissions require the entry of personally identifiable information (PII) for persons of interest. The LIMS has the ability to conform to the laboratories' policies for hiding or obfuscating PII. PII information that may be required includes the following: classification, unknown, first name/entity, last name, middle name, date of birth, sex, age, arrest number, suspect reference information, victim reference information, and State Identification Number.

Includes editable data fields and allows for future changes to the inputted data fields. All information can be set during the initial evidence intake process and be edited by specified users per permissions. the LIMS should maintain an auditable trail of changes.

The LIMS can automate data records entry via integration with other databases, internally or externally such as if the customer or case information has previously been entered for a prior submission or when the evidence information is in a customer database.

The LIMS has the ability to attach other records to the submission record:

- Photos of submitted evidence (the system provides the ability to modify any photo settings),
- Shipping documents, and
- Communication logs and emails.

Laboratory Workflow Initiation

The LIMS creates or initiates the following:

- Records of evidence submitted by the customers;
- Records of the chain of custody associated with submitted items, with the ability to transfer or store evidence within and between agencies;
- Labels for easier identification and movement of evidence items;
- The ability to push records to the applicable agencies/units for forensic testing;
- Notifications for certain needed steps in the transaction of entered evidence records;
- The ability to organize or view records, such as separate active and historical evidence records, so users are not overwhelmed with the growing volume of data entered;
- The ability to identify evidence that can be released from the laboratory once testing is completed;
- The ability to re-activate evidence records if items are resubmitted to the agency for testing;
- The ability to recall evidence from submitting agency for additional testing or submit additional evidence to be examined in the same case, without removing any previously entered information, such as communication logs, chain of custody records, and examination notes; and
- The ability for submitting agencies to provide relevant case management/triaging information, such as priority rationale and relevant court dates.

Evidence Sign-In and Review

This section describes the required LIMS functionality after evidence arrives at the laboratory.

Approval, Assignment, and Organization

The LIMS has the ability for users with the required permissions to review assigned evidence and approve the case for testing. When the case is not approved for testing, the LIMS has a deferral process with associated deferral letters or communications for rejected evidence that was submitted to the laboratory:

- Forwards evidence samples, items, and sub-items to different departments and ability to re-receive them while maintaining an accurate chain of custody;
- Resubmits evidence that has been released from the laboratory for additional testing;
- Assigns evidence to existing records;
- Differentiates between testing performed at different times; and
- Creates old case numbers to re-test evidence from old cases (e.g., pre-LIMS cases).

Usability

Corrects errors (e.g., reassigning evidence to different cases if incorrectly assigned or chain of custody corrections).

Has undo functions/actions to correct errors.

Generates audit trails.

Notifications

Notifies different departments that a specified list/batch of evidence is ready for examination (e.g., pull lists).

Assigns/de-assigns and notifies staff of workflow testing schedules and case completion.

Pushes cases approved for examination to a queue for analyst processing.

Evidence Examination

This section highlights several capabilities of LIMS in terms of evidence examination within the laboratory.

Selects cases pending examination from a queue and to assign or de-assign users from cases. The LIMS only allows examination when evidence is in the user's custody.

Edits exam notes after examination completed and those edits are traceable in an audit log. LIMS can undo functions or actions to correct for errors.

Integrates worksheets/forms. The LIMS provides a template builder for staff to create/edit bench notes, worksheets, or form templates with proper permissions. These templates should include selection options such as dropdown menus, freeform textboxes, and image uploads.

Sample Processing

This section provides a selection of LIMS capabilities related to sample processing in the laboratory.

The LIMS has a batch processing function that allows multiple items (with control samples) from multiple cases to be batched together for processing as a group. This may include physical and instrumentation processing steps. This function provides the following features:

Select or scan item barcodes to populate a batch;

- Move items through multiple steps of batch processing;
- Unload samples from a batch, break batches apart for subsequent steps of analysis, and remove subsequent tests that are not necessary for that sample;
- Store processing results in user-defined worksheets/templates;
- Upload batch results into the LIMS automatically for electronic storage within each specific case; and
- Verify/technical review.

The LIMS has the ability to attach documents (e.g., instrument files) to baches, create batch lists to show sample location, perform re-analysis or re-work at each step of the workflow, assign and de-assign users to batches, and view batch data.

The LIMS provides an easy-to-use sub-designation functionality (creation of sub-items from parent items) in the bench case notes for each unit, that automatically adds the newly created items to the main items list for the case when created and automatically adds the items to that assignment. When sub-designated items are added to the main items list, the solution also carries the agency item identification to the sub-designated items.

Case Management

Some case management features of a LIMS include linking related cases, attaching additional documents to case files, performing case expungement due to a court order, redacting data for a discovery or public records request, and generating other case-related reports (e.g., communication logs, batch reports).

Quality Assurance and Quality Control

This section provides a selection of quality assurance (QA) and QC functions that should be capability of a LIMS.

Reagent Management

Performs reagent management through the following:

- Creating reagents, lot numbers, and expiration dates but not permitting expired reagents to be used in a workflow unless there is a specific override;
- Creating barcode labels for reagents, including labels that have the proper identifying and hazard information;
- Tracking other attributes (e.g., vendor, catalog number);
- Documenting any QC check performed on that reagent for the life of the reagent;
- Editing reagent information after the record is created, update status (online/offline for use), track use in batches, track use in making other reagents;
- Tracking association with batches;
- Creating notifications (e.g., when reagents are about to expire); and
- Archiving/expiring or deleting reagents as needed.

Standard Management

Performs standard management:

- Tracking standards audit, standard lot numbers, and standards inventory;
- Tracking standards usage to include volume used (e.g., blind audit inventory check) and tracking of known amounts used;
- Documenting standard verification information;
- Tracking association with batches; and
- Maintaining DEA 222 forms.

Instrument and Equipment

Tracks instruments and other equipment in the laboratory through the following:

- Maintaining a list of all active and inactive instruments and equipment in the laboratory;
- Creating/maintaining/tracking usage of instrumentation to include maintenance and repair/service of instrumentation;
- Providing notifications for maintenance;

- Pulling a report by discipline, by instrument, or other factors such as a date range of all maintenance or repair events by tracking association with batches; and
- Classifying level of severity of repair or maintenance with the ability to create a dropdown menu for each type of activity performed. Free type should be available but used sparingly so that data can be aggregated by type of event. The majority should be dropdown items for standardized terminology.

Other QA/QC activities

Tracks and reports QA/QC activities through the following:

- Creating customizable queries associated with reagents, test batches, controls, and instruments;
- Tracking laboratory cleaning schedules and activities;
- Providing the ability to create reports/files for the reagent QC processes and different testing workflows (e.g., proficiency test workflow, competency test workflow, re-analysis workflow);
- Tracking non-conformities and generate non-conformity reports to ensure that the non-conformities can be linked to specific cases, if applicable;
- Logging and tracking court testimony, court travel, and court waiting times; and
- Logging and tracking preventative and corrective actions by generating reports by ongoing and cumulative QA activities.

Analytical Report Development, Review, and Approval

Captures, processes, and stores detailed information from analytical procedures and modules. These reports should allow for the sufficient capture of data to support any local, state, or federal reporting requirements.

The data captured are in a format that will support external sharing of the data by electronic data transfer or printing the data on paper.

The LIMS provides the ability to create and save report templates. The LIMS supports the review of the analytical report for quality, accuracy, and technical requirements. The LIMS supports all required reviews and corrections prior to final approval. Upon final approval, the LIMS allows users to lock analytical reports to prevent further edits or adjustments

Data Sharing

Supports data sharing as a core function. The LIMS supports interfaces that can import and export data.

All interfaces are compatible with databases such as National Crime Information Center (NCIC) and comply with national standards such as National Information Exchange Model (NIEM).

Training Module

This section discusses training module requirements for LIMS.

Create Training Cases in LIMS for Each Workflow/Module

Provides the ability for each unit to perform training via workflow/modules as per their function. The training workflow/modules cover each area of the laboratory, including both administrative and technical functions. Such functions include evidence submission and receipt, chain of custody, evidence analysis, reporting, and report notifications and delivery. The training workflow/modules are assigned to various users depending on their administrative or technical duties. These training case records are independent from operational case records.

Generate Record of Training

Creates training checklists for each user based on their administrative or technical duties. Attendance logs are maintained for each workflow/module completed by each user. Upon completion of each workflow/module, training certificates are generated showing the successful completion of each task by the user.

Management Reporting

This section discusses management reporting requirements of the LIMS.

Management Reporting Queries

The LIMS provides the end-user with the ability to query all data within the LIMS for the creation of management reports. These reports can run in a real-time environment without negatively impacting general operations and can be viewed electronically, exportable into a PDF, Excel, and Word document, and can be printed or pulled into software systems such as Power BI, iDashboard, or Tableau. The queries created by the end-user as management report templates can be saved for routine use.

Furthermore, the LIMS allows all queries to incorporate user-defined date range milestones (start and stop dates) using past, current, and future date fields and milestones like crime offense, evidence submission, assignment, analysis, technical review, administrative review, and report release. Finally, a “wildcard” option is beneficial when querying any data field; by using a pre-defined symbol in a query field, the LIMS returns all variations that include the root query.

Management Reporting Permissions

Provides the ability to assign permissions to individuals or groups to create, save, and access management report templates.

Management Reporting Data

Provides the ability for management reports to filter data by use of static values within data fields; all data entered into the system are maintained within or managed by the LIMS and are accessible by management reports. The LIMS provides an integrated tool to link specified data/metrics to dashboard software; common data/metrics to be displayed may include pending cases, analytical report output, case type, analyst, and turnaround time filtered by dates and other data fields. Through the use of an integrated tool, the end-user has the ability to schedule automatic updates to the specified data/metrics displayed on dashboard software or Excel.

Includes a standalone copy of the production database to be used for analysis/management reporting; the LIMS vendor ensures the production data in the standalone database are refreshed no less than daily and ensures that the use of the database will not negatively impact the production environment’s performance or functionality in any way.

Evidence Inventory

Provides a real-time inventory of all evidence that is filterable by current custody location; this query can be viewable on-screen and is printable. The LIMS also has an electronic inventory scanning process, whether performed manually or automatically such as with the use of RFID tags.

Budget Metrics

This section discusses budget metrics requirements of the LIMS.

Case Cost Analysis

The data for this section could be part of LIMS as user input fields, or they could come from other internal systems in which case the LIMS should have the ability to exchange data with those systems.

Personnel. Provides cost analyses associated with individual tasks and time spent performing tasks per individual and discipline. This personnel component can include the cost analysis associated with personnel (labor) expense per full-time equivalent; cost analysis associated with personnel (labor) expense per labor level (e.g., trainee, scientist, manager, director); cost analysis associated with personnel (labor) expense per forensic discipline area; and cost analyses associated with personnel (labor) expense as a proportion of total expenses.

Case Submissions. Provides cost analyses associated with case submissions. This includes cost per case, cost per item, and cost per sample and has the ability to extend to forensic discipline areas.

Asset Cost Analysis

Fixed Assets. Tracks fixed assets such as instrumentation, equipment, and software, including depreciation years and costs and procurement and funding source (e.g., grant, state). Cost metrics include price, unit price, quantity ordered, quantity received, shipping, subtotal, total, purchase order number, order number, vendor, vendor number, invoice number, ordered by, ordered for, received by, and date. The cost analysis associated with fixed asset expense can be provided as a proportion of total expenses.

Consumable Assets. Tracks consumable assets such as reagents and general laboratory supplies. Cost metrics include price, unit price, quantity ordered, quantity received, shipping, subtotal, total, PO number, order number, vendor, vendor number, invoice number, ordered by, ordered for, received by, and date. The cost analysis associated with consumable asset expense can be provided as a proportion of total expenses.

Quality Assurance. Tracks QC and QA activities, including proficiency tests, competency tests, standard verification, instrument maintenance, method validation, and training records.

NEXT GENERATION LIMS

Overview

The future of forensic LIMS requires both modernization and innovation to better position FSSPs for a growing number of challenges. In addition to defining the core functional requirements, Forensic Laboratory Needs Technology Working Group (FLN-TWG) offers a forward-looking strategy and identifies several new capabilities for the **Next Generation LIMS (NG-LIMS)**. This approach introduces concepts that are highly beneficial to both local operations and the broader forensic community and will enable more cost-effectiveness through a combination of proven and emerging technology. NG-LIMS extends core frameworks with enhancements to facilitate the forensic community's operational efficiency within increasingly complex and fragmented cyber environments. These will enable more advanced capabilities for rapid access, cross-identification, pattern recognition, anomaly detection, and data mining. To achieve a broader scope of objectives, sharing best practices and adopting data standards will help guide future implementation and operation. These may include fundamental features critical to all aspects of LIMS (such as the use of persistent digital identifiers) but may also introduce more advanced concepts, including data exchange through standard interoperable units (e.g., a forensics vocabulary, lexicon, or ontology). Although there are many successful examples on which this community can draw, forensic expertise will be key in determining the usefulness and priority for which of these will benefit LIMS the most.

Through years of operational experience with forensic LIMS, many shared lessons have demonstrated the high maintenance costs and challenges faced in evolving systems to meet stakeholder needs. The data management structure of LIMS is vitally important, as are the services that support access and exchange. This structure is both a need for a laboratory operation and a goal to provide interoperability between multiple organizations. LIMS stakeholders present different patterns in the use of these critical systems. The functional concepts of NG-LIMS should factor critical systems into the design of new interfaces for both human and machine points of entry to the system.

The goal of this report section is to provide guidance for future LIMS development and to facilitate discussions with FSSPs to support their use of this critical forensic system infrastructure. In addition to the primary functional requirements defined in the previous section, this may serve as a guideline to vendors for their development roadmaps. The NG-LIMS will strengthen evidence-based decision-making and underlying data for reported findings.

The FLN-TWG LIMS subcommittee has identified eleven areas of performance to consider to significantly improve and advance NG-LIMS operations: user experience, accessibility, human factors, architecture, data standards and best practices, process optimization, digital object management, operational performance, exchange protocols, prioritization controls, and analytics and performance. We summarize these areas below.

User Experience Design

NG-LIMS should be capable of optimizing incorporating user interface (UI)/user experience (UX) features. UI/UX design features to enrich interactions with the system and improve the end-user experience. One example of this is the use of a crime scene collection list to direct laboratory analysis automatically. This feature allows forensic analysts to view and manage the evidence collected from a crime scene easily and to prioritize the analysis of evidence based on its relevance to the case in real time before the case enters the laboratory.

LIMS should optimize other UI/UX features to improve the end-user experience. This can include features such as customizable dashboards, which allow analysts to view the information that is most relevant to their work, and intuitive navigation tools, which make it easy to find and access the information they need. The advantage of UI/UX features is that not every static system is intuitive to every user—but UI/UX features allow users to configure LIMS to their needs.

Overall, optimizing UI/UX features in FSSP laboratory management systems can help improve the efficiency and effectiveness of forensic analysis. By providing a user-friendly interface and intuitive tools for managing evidence and tasks, these systems can help analysts focus on their work and make the most of their time and resources rather than trying to navigate challenging, non-intuitive, and static user interfaces.

LIMS Accessibility

The design of NG-LIMS software, devices, services, or environments should ensure that all users, including those with disabilities or impairments, can use them effectively. NG-LIMS should make computer systems usable by as many people as possible, regardless of age, ability, or circumstance.

NG-LIMS should be equipped with a wide range of features and adaptations, such as screen readers for the visually impaired, speech recognition for those unable to use a mouse or keyboard, and text enlargement or high-contrast settings for those with visual impairments. Systems should also include interfaces that are easy to navigate and understand, provide alternative text for images, and ensure that websites and applications can be fully operated through keyboard input.

Easy to navigate and user-friendly interfaces should include clear labeling, intuitive design, and a user manual. User-friendly interfaces that allow users to customize system accessibility according to their needs (while maintaining appropriate security requirements) can make accessibility more useful—this can include customizable dashboards and workflows. User-friendly accessibility can be made more efficient by incorporating automation into the system. Automation and artificial intelligence (AI)/machine learning (ML) can improve efficiency by reducing manual tasks, including automating data entry, updates, and alerts.

NG-LIMS should break down barriers and create inclusive digital environments where everyone has equal access to information and functionality. Moreover, regular training and readily available support can help users understand how to use and access the system efficiently. This can include online tutorials, webinars, and a dedicated support team.

NG-LIMS can be accessible to external stakeholders to a degree; however, external users will be more restricted and have more limited accessibility than an internal user. In either case, ensuring the security of the system is crucial. Security and data integrity can be achieved by implementing strong encryption, multi-factor authentication, group controls, user profiles and roles, and regular security audits. Moreover, regular software updates can help improve efficiency and usefulness by adding new features, fixing bugs, and strengthening security. AI and ML embedded in NG-LIMS should be able to assist in security, user access, and regular updates.

Policy regarding the release of information from a LIMS to both internal users and external stakeholders should be strictly governed by confidentiality and data protection regulations. Although most FSSPs data are subject to public information policies, any release of or access to information to external users should require prior authorization from the appropriate management or legal personnel and compliance with legal requirements, ensuring that sensitive data are protected and only shared on a need-to-know basis. Consequently, accessibility to LIMS from both internal and external stakeholders should be strictly controlled.

Interoperability, both internally and externally, can be improved by ensuring the system can easily integrate with other software and systems. This can be achieved by using standard data formats and protocols and by providing APIs for third-party developers. This will be helpful when authorizing cross-organizational access, access to legal materials such as discovery requests and internal case data, and QA and QC checks.

With the increasing use of mobile devices, it is also important to ensure that the system is accessible on various devices and platforms. This can be achieved by adopting a responsive design that adjusts to different screen sizes and operating systems.

To ensure the system continues to be equipped with a wide range of features and adaptations, feedback mechanisms can help identify areas for improvement. This can include user surveys, feedback forms, and regular user meetings.

5. Quigley-McBride, A., Dror, I. E., Roy, T., Garrett, B. L., & Kukucka, J. (2022). A practical tool for information management in forensic decisions: Using Linear Sequential Unmasking-Expanded (LSU-E) in casework. *Forensic Science International: Synergy*, 4, 100216

Integration of Human Factors

Few decisions are made in FSSPs without human input. Even the decision to conduct a putatively objective test involves a human element. Decision-making can be conceptualized as evidence accumulation along a dimension, with the application of a threshold such that if the evidence exceeds the threshold a decision is made. With this structure in mind, factors such as contextual bias can be conceptualized as a shift in the threshold in response to external factors. That is, cognitive bias results in a potentially inappropriate shift in the decision threshold. Cognitive bias should be thought of as ubiquitous and not something that can be eliminated or trained away.

NG-LIMS should be transparent and capable of detecting areas of the system subject to cognitive bias. Capturing prior decisions or assumptions in decision processes would allow the FSSP environment to optimize system workflow and potentially strengthen its results and findings. NG-LIMS needs the capability to perform and monitor blind proficiency testing as one way to identify variations in decision thresholds across examiners or time. Extreme variation away from norms could be viewed as suboptimal and worthy of further investigation. Tracking assumptions of base rates will identify how those assumptions might affect decisions. For example, different decision thresholds might be adopted if a candidate impression is obtained from a database or from a detective.

NG-LIMS should document potential cognitive bias effects and work to minimize undue influence. NG-LIMS systems can facilitate this process by building in elements that track potential influencing information at every stage of the analysis. One potential framework for this approach is described in Quigley-McBride et. al. (2022), which outlines a set of questions asked in parallel with active casework procedures and documents the sources of information and assumptions that underlie each decision.[5]

LIMS provide an opportunity to provide both transparency and balance in observations and conclusions. Results should always be expressed in terms of support for each proposition rather than only stating the support for one proposition. NG-LIMS systems should allow for both propositions to be recorded for each analysis and then have fields that indicate the support for each proposition (or how likely the observations are under each proposition).

The use of digital assistance via AI shows some promise to detect inappropriate language. Just as Microsoft Word will now recognize grammatical errors and offer suggestions, AI applications can inspect written reports for instances where the forensic practitioner has offered conclusions about the probability of propositions rather than the probability of observations given two propositions. Such text should be verified by a human examiner and possibly marked as AI-generated in the report.

LIMS Architecture

One of the overarching concepts for developing an effective system architecture is FAIR Data Principles.[6] The forensics community is faced with many similar challenges to other disciplines, given the explosive growth in digitalization. Barriers to discovery, access, interoperability, and reuse are well-known. With the adoption of FAIR, NG-LIMS systems will begin to address gaps and limitations within core frameworks to ensure the highest utility of the system and return on investment. It is noteworthy that FAIR does not imply "open" but rather "as open as possible, as closed as necessary." Critical security and access controls may co-exist in a FAIR system environment.

6. Wilkinson, M., Dumontier, M., Aalbersberg, I., Appleton, G., Alton, M., Baak, A., Blomberg, N., Boiten, J. W., Bonino de Silva Santos, L., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T, Finkers ,R., Gonzalez-B,eltran, A., et al. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data 3*, 160018. https://doi.org/10.1038/sdata.2016.18Williams, S., Taylor, M., Mehta, A., & Jeffrey, I. (2014). RFID technology in forensic evidence management: An assessment of barriers, benefits, and costs. NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology. https://doi.org/10.6028/NIST.IR.8030

FAIR—Findable, Accessible, Interoperable and Reusable—introduces terminology that can be interpreted in relation to many LIMS components. In evaluating the level or degree to which a system is FAIR, it is often left to the community's discretion to specify precisely how each aspect of FAIR is applied; thus, in this section we provide more specific examples toward building a FAIR LIMS solution.

Data system architectures are expanding areas of applications that challenge LIMS platforms and introduce technology that may fall outside the scope of the traditional laboratory environment. These include some newer methods such as use of open-source software in addition to modern databases. NoSQL DB, and open-source databases such as PostgreSQL, enable richer data asset management, machine access, and indexing, thereby providing more flexibility in structuring holdings and interfaces to application technology. Cloud storage, cloud resources, and software containerization provide the ability to reduce the maintenance costs of physical hardware and facilities. As zero-trust security models are put in place to protect against cyber threats, implementing data system architectures comes with its own challenges for hosting and deployment. Commercial platforms often provide these resources as part of their NG-LIMS and will require vigilance in adapting LIMS to securely configured accessibility goals.

Data Standards and Best Practices for LIMS

Modern digital standards and best practices for NG-LIMS solutions are vital to achieve the needs of the future. Many disciplines are increasing their dependency on data acquisition and IT, yet there are often different functional priorities between the systems generating the data and user inquiry, which relies on finding and accessing the information they are seeking. With the introduction of data standards, other disciplines such as biotechnology and space science have demonstrated that functional environments yield significant benefits in both cost savings in addition to serviceability to their respective stakeholder communities. We envision that adopting standards and sharing best practices across the forensic community would lead to similar results for laboratories managing NG-LIMS. NG-LIMS is not limited to IT alone; NG-LIMS introduces emerging concepts for digital asset management and intersects with the emerging field of data science. Forensic laboratory science also has unique requirements driven by stringent environments for traceability, validation, and trust in addition to subject matter expertise in analysis and equipment use. Developing forensic-oriented data standards and integrating them with an agreed upon community best practice will reinforce usability and simultaneously provide secure gateways for machine and human communication. This guidance document does not attempt to dive into standards processes, but it does introduce a few key and fundamental concepts as a basis for the community to engage in further efforts.

Building Common Forensic Data Definitions

The implication of standardizing data can be formidable in the laboratory environment given that organizational infrastructure, LIMS solutions, caseloads, and timelines all vary. In addition to the LIMS functional requirements and aspirations of NG-LIMS discussed here, operational environments continue to rely on proprietary aspects for managing data entry, database structures, field definition (dependent on equipment and supplies), and technology. Analysts may also annotate text according to their individual level of expertise or procedure. Although FSSPs have many common practices and procedures, their independent operations and commercial reliance introduce variations that prevent reuse of information in practice. Adopting common data definitions and data use models would foster consistency for exchange across multiple laboratories and within laboratory procedures. It is important to note that implementing common definitions for forensics data does not mean modifying the LIMS infrastructure but can also be achieved by adapting LIMS content through lighter weight services that map content to common definitions.

With the transformation of LIMS to digital technology alongside an emergence of new forensic science disciplines, identifying common representations of data managed and used by LIMS allows independent tools to perform validation. Currently, interoperability is noticeably lacking in forensics, preventing exchange of data across jurisdictional boundaries and internally between disparate systems connected to an individual laboratory. NG-LIMS presents a compelling rationale for adopting common and shared data definitions because they will become more urgently needed for automation and machine readability as digital holdings continue to explode in capacity. Commonality in data and related processes lets FSSPs shar technology, thus creating a more viable *economy of scale* across the community and can address multiple scenarios. This can translate to significant cost savings in maintaining and operating LIMS over time. NG-LIMS–related use cases are introduced throughout the core system functionality in addition to this section, including laboratory analysis, investigative practice, court scenarios, and discipline science.

Agreement on common forensic data definitions from the forensics community, FSSPs, and the criminal justice system is needed. These definitions would require standards references where possible (e.g., the Organization of Scientific Area Committees for Forensic Science (OSAC) Latent Fingerprint, DNA FBI quality standards, ISO/TC 272 Forensic Sciences). New terminology introduced by NG-LIMS systems would apply to all user profiles of the system, including analysts, investigators, and administrators.

Another more formalized data definition to consider would be a forensic laboratory *registry*, or a catalog of several types of organizational data–related assets. This approach provides a point of entry to a community and often leads to further definition of more specific areas (e.g., lexicon, semantic schemas) for the associated registry catalog entries. Organizations such as American Society of Crime Laboratory Directors (ASCLD) along with the Instrument Knowledge (FRC) Framework could facilitate an LIMS registry. Although this work is currently based on documents, conversion and extension to a machine-readable format would be highly beneficial and complement more detailed data exchange.

Digital Object Management

One of the most basic challenges in any LIMS system is finding reliable and complete data resources over time. This may be challenging for various reasons, including lack of attention to curation and content maintenance. Many utilities are now put in place into LIMS to safeguard recovery and access; however, completeness and longevity present more costly and complex issues. LIMS solutions commonly use system-specific identifiers. This may present challenges for migrating content to another system, be constrained to a set structure, or limit use by other commercial systems or tools. Standard digital Persistent Identifiers (PIDs) assigned to sources of data address these basic problems and serve as a digital asset building block for more complex functionality. There are numerous examples of standard PIDs: Digital Object Identifier (DOI), Handle (based on the Handle System), Archival Resource Keys (ARKs) , and Open Researcher and Contributor ID (ORCID). DOIs and ORCIDs are globally unique and used for publication citation and authorship. The Handle System is a global name server and an underlying resource for the DOI system. It supports a network of handle servers, which can be managed by an organization to issue Handle PIDs under a unique handle prefix. The ARK ID has more flexibility and is based on a decentralized model with a clear specification. ARK IDs can be used to issue PIDs to identify anything digital, physical, or abstract. Communities can also come together to define their own structure. An example of this is a PID schema for instrumentation (PIDInst), a Research Data Alliance working group recommendation developed for unique identification of instrumentation used in the sciences. The forensic LIMS environments would benefit from formulating similar constructs to identify units of operation. PIDs are undoubtedly a key digital component to creating networks of linked data and contribute to the advancement in use of knowledge graphs and federating distributed sources of information. These concepts collectively form the basis of a *data mesh*, a network of digital information across designated community spaces.

Regarding NG-LIMS, there are several important properties of PID implementation, and together they support the key goal of disambiguating data. What this means simply is that a data source can be reliably found and validated when the assigned PID is used in its optimal capacity. Reports can embed PIDs that resolve directly to LIMS access portals to allow FSSPs to immediately validate analysis and report content. Best practices that take this a step further include actions that perform validation and thus lead to trusted data sources. A PID, as the name implies, is persistent over time. It will support NG-LIMS aspirations for process automation through properties such as uniqueness, machine-readable formats (e.g., a URL, and metadata), which includes source location. LIMS system identifiers are often labeled as PIDs, yet the PID may no longer work when there is a change in the data, or the system performs an administrative operation. Thus, it is important to have clear use cases and defined patterns in which a PID is used to preserve long-term findability.

7. Williams, S., Taylor, M., Mehta, A., & Jeffrey, I. (2014). *RFID technology in forensic evidence management: An assessment of barriers, benefits, and costs.* NIST Interagency/Internal Report (NISTIR), National Institute of Standards and Technology. https://doi.org/10.6028/NIST.IR.8030

Another context for PID use highly beneficial to laboratory environments is sample provenance tracking. Provenance identifies the sample source and each subsequent operation performed on the sample. With proper PID use, processed samples can be interpreted for accuracy and analyzed throughout the chain of activities that generated data. With LIMS, access restrictions or privacy may prohibit the direct resolution of a sample PID; however, within the context of controlled access or anonymized data, a PID may provide a capability to resolve and navigate a complete dataset.

A PID also may serve in the generation or persistence of linked information, such as linked cases, linked evidence, or geolocation patterned events. Looking ahead to the description of concepts for defining shared forensic data definitions, PIDs may be assigned to composite data types or represent constituent pieces of information. The granularity and assignment of PIDs is best determined by understanding of usage patterns and considering what level of flexibility in the system is beneficial for both defining and constructing unambiguous sources of information. The ability to transfer of trusted information to an external service or analytical tool for processing and mining will be a key factor when building NG-LIMS.

Operational Performance

LIMS are designed to streamline the workflow of FSSPs by automating processes and providing a centralized platform for managing cases. One of the key features of these systems should be the ability to customize and configure the workflow to meet specific laboratory needs. This should include defining steps in the workflow; assigning workflow tasks; and setting notifications and alerts to ensure priority cases, samples, and crucial deadlines such as court dates are met.

In addition to customization and configuration, NG-LIMS should also offer extensibility, which allows laboratories to add new functionality and features as needed without workflow disruption. This can include integrating other systems, such as Invita STACS®Casework and STACS®Database, Foray™, Mideosystems® CrimePad, or Sexual Assault Kit (SAK) tracking or other case management or evidence tracking systems, or it can include adding new features like analysis tools or techniques. By providing a flexible and extendable platform, LIMS can adapt to changing environmental conditions, needs, and requirements over time.

New Technology

Future LIMS should implement technology (e.g., Radio Frequency Identification [RFID], WIFI, Bluetooth) to automate physical evidence tracking. Using tracking technology such as RFID on evidence tags is shown to improve the efficiency and accuracy of evidence management. RFID[7] tags can be attached to evidence items, allowing them to be tracked throughout the entire chain of custody, including in lockers and personnel possession. This can help ensure that evidence is not lost or misplaced and can also provide a detailed record of who handled the evidence and when. This form of tracking can also be used to automate the process of checking evidence in and out of the laboratory. When evidence is received, it can be scanned and automatically added to the laboratory's inventory system. When evidence is checked out, the tag can be scanned again, providing a record of who took the evidence and when. Although this seems like barcoding, which is currently prevalent in most FSSPs, more modern forms of tagging transmit data wirelessly. These methods have several advantages over using barcodes, including the ability to read multiple items at once, read items without line of sight, and store more data. It also allows for real-time inventory tracking and monitoring, which can improve evidence tracking efficiency and reduce errors. Overall, tracking technology is a more advanced and versatile technology than barcodes, making it a better choice for NG-LIMS.

Tracking technology tags can also be used to monitor the condition of evidence items. For example, temperature and humidity sensors can be embedded in the tag, allowing FSSPs to monitor the environmental conditions in which the evidence is stored. This can help ensure that evidence is stored in optimal conditions, reducing the risk of degradation or contamination.

Process Optimization

NG-LIMS can be optimized to automatically generate and deliver reports by standardizing report templates that can be used across distinct types of cases and forensic disciplines. This will ensure consistency and reduce the time required to create new reports. Integrating NG-LIMS with analytical instruments will automatically import data and results. This will reduce the need for manual data entry and minimize errors. Developing automated workflows can allow NG-LIMS to trigger report generation and delivery based on pre-defined criteria. For example, a report can be automatically generated and delivered when a case is closed or when a specific test result is obtained. Using in-house and cloud-based solutions will enable remote access to the LIMS and reports and will allow authorized personnel to access reports from anywhere, at any time. NG-LIMS can be optimized to implement AI algorithms that can analyze data and generate reports automatically. These algorithms can be trained to recognize patterns and trends in data and generate reports based on pre-defined criteria or trigger critical QA reviews based on reporting trends. In the future, natural language processing can enable LIMS to understand and interpret human language. This will allow an automated NG-LIMS to generate more natural and human-like reports. By integrating the NG-LIMS with ML models that can learn from data and improve over time, the NG-LIMS can learn to create accurate and relevant reports automatically. Using predictive analytics to forecast future trends and outcomes, NG-LIMS should be able to generate non–case-specific reports, such as those for metrics, which are more forward-looking and actionable.

The lifecycle of a case involves multiple processes, and tracking case status over time is currently inefficient (e.g., pending court decision and active subpoena requirements for analysts).

To optimize NG-LIMS for Quality Management System corrective action monitoring, automated data analysis tools that can detect problems and inconsistencies in data can be developed. These tools can be programmed to identify outliers, missing data, and other anomalies that may indicate quality issues. Additionally, developing dashboards and visualizations in NG-LIMS that provide a real-time view of quality metrics will enable users to quickly identify trends and patterns that may indicate quality issues. Real-time monitoring tools, such as statistical process control charts, or Pareto charts, can be developed that can track data as they are generated and identify quality issues as they occur. Furthermore, automated NG-LIMS alerts that notify users when quality issues are detected can be sent via email, text message, or other communication channels. This will enable immediate corrective action. Soon, ML and predictive analytics algorithms can be developed that can learn from data and identify patterns that may indicate quality issues or quality issues that may be about to occur. These algorithms can be trained to recognize specific types of errors and inconsistencies.

Soon, LIMS should be able to leverage emerging AI/ML to optimize user interface/user experience features like tracking technology and customizing and configuring processes. AI/ML algorithms can analyze data from various sources such as case urgency, resource availability, and team workload; validations and research being conducted; or projects being managed and assist in determining the optimal order in which tasks should be completed to help ensure the most important work is completed first while minimizing delays and maximizing efficiency.

In addition to prioritizing controls, AI/ML can also be used in workflow management to automate repetitive tasks and improve accuracy. For example, AI/ML algorithms can be used to classify and categorize evidence or evidence samples automatically, reducing time and effort. Importantly, AI/ML can also be used to identify patterns and anomalies in workflows, helping forensic analysts identify potential connections among cases, subjects, geolocations, or data in general.

Overall, the use of AI in NG-LIMS can help improve the efficiency and accuracy of the workflow by smoothing the process, eliminating friction points, and providing intelligent prioritization controls. As AI/ML evolves, it is likely that we will see even more advanced applications in NG-LIMS.

Exchange Protocols

Earlier in this report, we introduced functional requirements that allow APIs to be developed for interfacing with the LIMS platform. These are essential for operation and tools to ingest, access, and connect across the platform. However, to address the goals outlined for NG-LIMS and achieve FAIR use, these services need to be thought of as more than just an API. For the LIMS stakeholders to make optimal use of this highly valuable resource, a standard or common protocol specification should be developed and described. A standard protocol typically includes both query and response formats designed to support the intended user's needs. This protocol may be accompanied by shared toolkits for explaining information and validation operations.

In the simplest form, intra-operability within a localized LIMS environment would support a pluggable framework capability. This refers to the capability of a LIMS to support integration with a suite of tools. Ideally, this would not be limited to an individual commercial framework and would allow for external tools, such as those described in the NG-LIMS **Analytics and Performance** section, to interface with the LIMS system through a secure interface. A pluggable framework modular design can help maintain an LIMS. For example, an internal system change, such as a database table, may occur while the services which access the database continue to operate. This form of decoupling provides flexibility for operations and can narrow down which parts of the system need to be updated. Interoperability for NG-LIMS requires more robust use of API specifications and allows integration with other services, tools, and analytics, to form a richer digital investigative ecosystem.

Prioritization Controls

Prioritization controls are an important aspect of workflow management. With many cases and tasks to manage, it is essential to have a system in place that can prioritize work based on factors such as case urgency, resource availability, and team workload. LIMS provide tools for managing the workflow queue, including the ability to assign priorities to tasks, track progress, and reassign tasks as needed to ensure that the most important work is completed first. In addition to managing case workflow and prioritization, robust NG-LIMS should also be able to include prioritizing non-casework tasks such as validations, research, and training needs. By providing these controls, LIMS help ensure that cases are processed efficiently and effectively while maintaining the highest standards of quality and accuracy.

Analytics and Performance

Key performance indicators (KPIs) and analytics are crucial in any organization, including FSSPs, because they provide valuable insights into operational efficiency, resource allocation, and decision-making. By leveraging performance analytics, such as those used in Project FORESIGHT, laboratories can identify patterns, trends, and anomalies in data, enabling them to make informed decisions, improve outcomes, ensure quality of service, and facilitate continuous improvement.

The crucial role of analytics and performance measurement in NG-LIMS is paramount and something many current LIMS are lacking. As FSSP continue to evolve and face increasing demands for efficiency, accuracy, and transparency, integrating advanced analytics and performance measurement tools is essential.

The benefits of incorporating analytics into a LIMS include improved decision-making, enhanced operational efficiency, and the ability to identify trends and patterns in forensic data. Additionally, analytics and KPIs can measure the effectiveness and efficiency of an LIMS itself, enabling laboratories to optimize their processes, allocate resources effectively, and meet the ever-growing demands of forensic science.

Building a complete, fully featured statistics package into a LIMS with graphical capabilities, KPIs, and trend analysis is of paramount importance. Such a comprehensive analytics module can revolutionize the way forensic data are analyzed, interpreted, and used. Moreover, laboratories can uncover hidden patterns, correlations, and anomalies in the LIMS data by leveraging statistical techniques.

KPIs can include traditional Project FORESIGHT metrics such as turnaround time, case backlog, resource utilization, and QC measures, but NG-LIMS will hopefully include many more undiscovered or ML-produced KPIs. By tracking these metrics, laboratories can identify bottlenecks, optimize workflows, allocate resources effectively, and ensure timely delivery of results. Furthermore, KPIs help align laboratory performance with organizational goals and objectives and strategic plans, providing a framework for continuous improvement and strategic decision-making.

A fully featured statistics package incorporated into LIMS should be equipped with graphical capabilities such as dashboards to further enhance data interpretation. Dashboards present complex information in a visually intuitive manner, making it easier for users to understand and communicate findings. Furthermore, by incorporating user interface (UI)/user experience (UX) features into graphical statistics packages, LIMS can improve an end-user's experience and allow them to view the information most relevant to their work by providing intuitive navigation tools, which make it easy to find and access the information they need. In the near term, some of this work could be accomplished by creating API plug-in opportunities for existing tools such as PowerBI, Tableau, or DOMO. Regardless of the API tool implemented, it should have the ability to display visual representations of data, track performance metrics, and identify trends. For example, a manager could query the system one time or set up a dashboard to monitor the intake of items by number of cases, case type, or item type in real time.

An NG-LIMS that can perform trend analysis is a powerful tool that allows laboratories to identify patterns and anticipate future demands. By analyzing historical data, laboratories can identify emerging trends, anticipate workload fluctuations, and allocate resources proactively. Trend analysis also aids in identifying potential areas for process improvement, enabling laboratories to stay ahead of evolving forensic challenges and adapt their operations accordingly.

Performance Optimization

LIMS should soon be able to leverage emerging AI and ML to enhance the measurement of KPIs and trends significantly. AI and ML algorithms can leverage the vast amount of data collected by the LIMS to provide valuable insights and improve the accuracy and efficiency of performance measurement.

By applying AI and ML algorithms to KPIs such as backlog, turnaround time, input, output, and other traditional metrics, an AI/ML-enhanced LIMS can identify patterns, correlations, and anomalies that may not be immediately apparent to human analysts. These algorithms can automatically analyze large datasets, detect trends, and predict future performance based on historical data. This enables laboratories to address potential bottlenecks proactively, optimize workflows, and allocate resources effectively to meet increasing demands. The key feature is the ability to automate large data analyses. Human users are ill-equipped to intuit the complex searching strings necessary to enable a LIMS to identify patterns and discover complex data correlations.

Moreover, AI and ML can help identify factors that contribute to performance variations. By analyzing various data points, such as case complexity, analyst workload, and case and sample allocation, these algorithms can identify the key drivers behind performance metrics. This information can be leveraged to develop targeted strategies for improvement, such as optimizing staffing levels, implementing training programs, or streamlining processes.

Additionally, AI and ML can assist in real-time monitoring and alerting. By continuously analyzing data from the LIMS, these algorithms can detect deviations from expected performance levels and trigger alerts or notifications. This allows laboratory managers to promptly address issues, mitigate risks, and maintain high quality standards.

User Customization

NG-LIMS should be able to quickly assimilate new tools that come from external developers or other LIMS customers. Various applications should be able to be implemented and plugged in, as opposed to reprogramming the root system. Tools like Jupyter Notebook could be employed to share programming code that others have developed or to share plug-in tools that do not require root system reprogramming. Jupyter Notebook is an open-source web application that allows users to create and share documents containing live code, equations, visualizations, and narrative text. It is widely used in data science and analysis because of its interactive and collaborative nature. Incorporating Jupyter Notebook or another similar tool into LIMS can bring several advantages and enhance the capabilities of the system.

One advantage of incorporating Jupyter Notebook into an LIMS is its interactive and exploratory nature. Users/developers can write and execute code in real time, allowing for immediate feedback and iterative analysis. This interactivity enables users and developers to experiment with different analysis techniques, visualize data, and gain deeper insights into LIMS functionality and workflows, which can improve LIMS functionality in real time.

Tools such as Jupyter Notebook support the integration of external libraries and tools, which can help expand LIMS capabilities expediently. Users can leverage popular data analysis libraries, ML frameworks, and visualization tools within the notebook environment. This allows for advanced analytics, pattern recognition, and predictive modeling directly within the LIMS, enabling users/developers to extract more value from the LIMS and data contained within to improve outcomes. For example, LIMS can identify atypical analyst behavior.

Knowledge Graphing

NG-LIMS should also perform analysis through knowledge graphing to show—either visually or through ML—relationships and connections that may not be previously understood. One example would be criminal intelligence where a network of relatedness could be established between cases or information coming from related cases. This could potentially be very valuable during case intake where a visual knowledge graph could be developed to see how the case might potentially connect to other cases in the laboratory or trends that are being seen by the laboratory (e.g., gun crimes linked to a certain geographical area or sexual assault cases linked to a certain date range every year or a certain holiday).

This is another area where AI and ML can play a crucial role. These technologies can help identify patterns and correlations, leading FSSPs to valuable insights. For example, FSSPs may be able to analyze chain of custody data from multiple cases and identify similarities or connections between them. By analyzing factors such as the time, location, personnel involved, and evidence types, the system can identify potential links between cases that may have otherwise gone unnoticed and arrange or sort those cases such in a manner that that they could be examined with potentially links or seriality in mind. Moreover, patterns in result interpretation or conclusions by individual scientists that may have otherwise gone unnoticed can be analyzed for non-conformities or inconsistencies as well. The largest impact may be an LIMS' ability to analyze large datasets automatically and continuously in real time to uncover previously unknown relationships and correlations without human foresight or initiative to conduct such searches and without the need for the human to sense the relevant search strings to uncover relationships, patterns, and correlations.

Automating the analysis of large datasets can significantly enhance the efficiency and accuracy of KPIs and uncover patterns and correlations in the data. In addition to supporting the quality science conducted in an FSSP, NG-LIMS could provide actionable insights, assist the laboratory in making informed decisions, improve outcomes, ensure the quality of service, and facilitate continuous improvement.

8. Maldonado, B. (2012). Study on developing latent fingerprints on firearm evidence. *Journal of Forensic Identification*, 62, 425–429.

Advancements in Forensic Science

In consideration of many advancements in the forensic science domain, NG-LIMS is envisioned as both a resource for users and clients and as a system that integrates new and emerging areas of science. The digital NG-LIMS landscape provides a form of normalization across discipline boundaries. For example, physical and digital crime scene investigations operating independently can exchange and link relevant data together. New analytical methods in the physical laboratory, including operational units or process steps (e.g., associated reagents), can be instantly digitally compared for evaluation in assessments for performance and accuracy. Access to databases through services for DNA analysis will be immediate. Extending this across the full lifecycle of forensics investigation, NG-LIMS can be leveraged at all levels of law enforcement, including the judicial processes. It will play an increasingly key role in evolving discipline-specific areas, serving real case scenarios and cross-cutting use cases, and helping make breakthroughs in methods for solving challenging forensics problems. The disciplines of DNA, ballistics, digital forensics, biometrics, drugs and toxicology, trace evidence, fingerprints, and pattern evidence are all making significant improvements that will intersect with the LIMS digital asset functionality.

Forensic science complements the capabilities of NG-LIMS and helps reinforce the need for shared best practices. This has been demonstrated through discipline-based comparative studies, which find variations in laboratory methods that have a direct relationship to evidence recovery.[8] With NG-LIMS, cross-laboratory analysis can become immediate through interoperable services and common data formats. This example is just one of many discipline areas where NG-LIMS will benefit in gaining faster understanding, sharing of laboratory analysis, and ability to address known challenges for laboratory operations.

More data-intensive sciences are emerging in FSSP investigation, driven by digital forensics with complex networks of Internet of Things devices, such as temperature monitoring systems. The research communities are struggling to keep pace with forensic application in the context of digital technology. This discipline is accelerating in practice across all facets of law enforcement, including the intel community. The ability to exchange, interoperate, and extract key information from this complex cyber space is typically beyond the scope of individual laboratory operations; however, it is beneficial for NG-LIMS to provide interfaces both as a data provider and consumer to support many investigative scenarios. New standards in digital forensics, such as Cyber-investigation Analysis Standard Expression (CASE), support a growing community of practice and advancements in the development of structured forensic ontology, further reinforcing traceability across the network of knowledge. Given the volumes and magnitude of data generated in the digital forensics discipline area, digital asset management—out of necessity—requires many of the capabilities described in NG-LIMS. Innovative approaches, such as Digital Forensics as a Service implementation provide an efficient model to replace traditional investigative practices that struggle with backlogs and stove-pipe processes with a service model to perform direct query of the digital material with flexibility, supporting exploration of different hypothesis. One can easily translate this capability to other forensic discipline areas given the NG-LIMS capabilities for services and accessibility.

Interdisciplinary forensic science and bridging across various communities of practice will increasingly become more common. Organizations are both creating and benefiting from more real-time data, such as the Overdose Mapping and Application Program (ODMAP), serving High Intensity Drug Trafficking Areas (HIDTA). The ODMAP demonstrates a benefit not only to the investigative community but also the public health system. Through discovery and exchange, FSSPs can also benefit from this type of service access and contribute to goals for preventing drug use and apprehending criminal activity. Challenges in data anonymity, privacy, and security will all come into play with increased data exchange. Fortunately, these challenges are not unique; pursuing collaborative partners, including vendors and other discipline laboratory environments, is needed for the adoption of NG-LIMS in the FSSP community.

Conclusion and Next Steps

The NG-LIMS key areas are intended to encourage LIMS vendors and laboratory directors to consider these concepts as the community moves forward with future investments. Given the complexity of the LIMS environment, subject matter expert turnover, and resource constraints, LIMS have become inflexible. NG-LIMS implementation strategies provide FSSPs with renewed agility and will avoid previous challenges with interoperability. There will also be new opportunities, introduced through system service flexibility, to integrate innovative tools to plug into LIMS for analysis, instrumentation, or workflow. With modularity as a core feature of the NG-LIMS architecture, we envision that systems will more readily adapt to new discipline needs and integrate in new features and functionality.

The FLN-TWG LIMS subcommittee also recommends forming a community of practice that includes vendors, laboratories, and research organizations to foster adoption and best practice for these highly valuable forensic LIMS resources. Developing shared practice and standards as part of this community of practice will help distribute knowledge and improve operations across the forensic science community.

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