Designation: E1578 – 13

Standard Guide for Laboratory Informatics[1]

This standard is issued under the fixed designation E1578; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide helps describe the laboratory informatics landscape and covers issues commonly encountered at all stages in the life cycle of laboratory informatics from inception to retirement. It explains the evolution of laboratory informatics tools used in today's laboratories such as Laboratory Information Management Systems (LIMS), Electronic Laboratory Notebooks (ELN), Scientific Data Management Systems (SDMS), and Chromatography Data Systems (CDS). It also covers the relationship (interactions) between these tools and the external systems in a given organization. The guide discusses supporting laboratory informatics tools and a wide variety of the issues commonly encountered at different stages in the life cycle. The sub-sections that follow describe details of scope of this document in specific areas.

1.2 *High-Level Purpose*—The purpose of this guide includes: *(1)* helping educate new users of laboratory informatics tools, *(2)* provide a standard terminology that can be used by different vendors and end users, *(3)* establish minimum requirements for laboratory informatics, *(4)* provide guidance for the specification, evaluation, cost justification, implementation, project management, training, and documentation of the systems, and *(5)* provide function checklist examples for laboratory informatics systems that can be adopted within the laboratory and integrated with the existing systems.

1.3 *Laboratory Informatics Definition*—Laboratory informatics is the specialized application of information technology aimed at optimizing laboratory operations. It is a collection of informatics tools utilized within laboratory environments to collect, store, process, analyze, report, and archive data and information from the laboratory and supporting processes. Laboratory informatics includes the integration of systems, the electronic delivery of results to customers, and the supporting systems including training and policies. Examples of laboratory informatics include: Laboratory Information Management Systems (LIMS), Electronic Laboratory Notebooks (ELNs), Chromatography Data Systems (CDS), and Scientific Data Management Systems (SDMS).

NOTE 1—Laboratory informatics scope encompasses multiple technical solutions or systems. The division between these system categories continues to soften as functionality continues to be added to each of them. LIMS were originally created to address the laboratories' need to manage laboratory operations and data, provide traceability for all laboratory samples and equipment, and ensure that laboratory procedures are followed. ELNs, on the other hand, were originally created to meet the scientists' need to document their experimental design, execution, and conclusions in an electronic format instead of in a paper notebook. SDMS was created to provide a repository of all scientific data files and results regardless of instrument type. The current definitions of each of these system categories are far more encompassing.

1.4 *Scope Considerations When Selecting and Implementing Laboratory Informatics Solutions*—Many laboratories have determined that they need to deploy multiple laboratory informatics systems to automate their laboratory process and manage their data. Selection of an informatics solution requires a detailed analysis of the laboratory's requirements rather than by choosing a product category. It is important to include representatives from Information Technology (IT) and Subject Matter Experts (SMEs), who understand the needs of the laboratory, to be involved in the selection and implementation of a laboratory informatics system to ensure that the needs of the laboratory are met and that IT can support it. Customers (internal and external) of laboratory information should also be included in the laboratory informatics solution design, to ensure there is full electronic integration between systems.

1.5 The scope of this guide covers a wide range of laboratory types, industries, and sizes. Examples of laboratory types and industries are listed in the following:

1.5.1 *General Laboratories:*

1.5.1.1 Standards (ASTM, IEEE, ISO), and

1.5.1.2 Government (EPA, FDA, JPL, NASA, NRC, USDA, FERC).

1.5.2 *Environmental:*

1.5.2.1 Environmental Monitoring.

1.5.3 *Life Science Laboratories:*

1.5.3.1 Biotechnology, and

1.5.3.2 Diagnostic.

1.5.4 *Healthcare Medical:*

1.5.4.1 Devices,

1.5.4.2 Pharmaceuticals vet/animal,

1.5.4.3 Public health, and

[1] This guide is under the jurisdiction of ASTM Committee E13 on Molecular Spectroscopy and Separation Science and is the direct responsibility of Subcommittee E13.15 on Analytical Data.

Current edition approved Aug. 1, 2013. Published November 2013. Originally approved in 1993. Last previous edition approved in 2006 as E1578-06. DOI: 10.1520/E1578-13.

1.5.4.4 Hospital LIS.
1.5.5 *Heavy Industry Laboratories:*
1.5.5.1 Energy and resources,
1.5.5.2 Manufacturing and construction,
1.5.5.3 Materials and chemicals, and
1.5.5.4 Transportation and shipping.
1.5.6 *Food and Beverage Laboratories:*
1.5.6.1 Agriculture,
1.5.6.2 Beverages,
1.5.6.3 Food, and
1.5.6.4 Food service and hospitality.
1.5.7 *Public Sector Laboratories:*
1.5.7.1 Law enforcement,
1.5.7.2 State and local government,
1.5.7.3 Education, and
1.5.7.4 Public utilities (water, electric, waste treatment).

1.6 *Integration*—The scope includes communication and meaningful data exchange between different laboratory informatics tools and other external systems (document management, chromatography data systems, laboratory instruments, spectroscopy data systems, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), Investigations/Deviations and CAPA management systems), and other integrated business systems (for example, clinical or hospital environments) provide significant business benefits to any laboratory and is discussed at a high level in this guide.

1.7 *Life Cycle Phases*—The scope of this guide is intended to provide an understanding of laboratory informatics tools' life cycle from project initiation point to retirement and absolution. This guide was designed to help newer audiences in understanding the complexity in the relationships between different laboratory informatics tools and how to plan and manage the implementation project, while seasoned users may use the different life cycles to maintain existing laboratory informatics tools. Integrating additional tool(s) to the existing one(s) in today's evolving laboratory informatics world adds constraints that need to be considered. The lifecycle discussion includes both the laboratory informatics solution lifecycle as well as the project lifecycle, which describes steps to a laboratory informatics solution.

1.7.1 The product lifecycle encompasses a specific laboratory informatics system and the expected useful life of that system before it needs to be replaced or upgraded.

1.7.2 The project lifecycle encompasses the activities to acquire, implement, operate, and eventually retire a specific laboratory informatics system.

1.8 *Audience*—This guide has been created with the needs of the following stakeholders in mind: *(1)* end users of laboratory informatics tools, *(2)* implementers of laboratory informatics tools, *(3)* quality personnel, *(4)* information technology personnel, *(5)* laboratory informatics tools vendors, *(6)* instrument vendors, *(7)* individuals who shall approve laboratory informatics tools funding, *(8)* laboratory informatics applications support specialists, and *(9)* software test/validation specialists. Information contained in this guide will benefit a broad audience of people who work or interact with a laboratory. New users can use this guide to understand the purpose and functions of the wide varieties of laboratory informatics tools as well as the interactions between these tools with external systems. The guide can also help prospective users in understanding terminology, configurations, features, design, benefits and costs of these different laboratory informatics tools. Individuals who are purchasing (a) specific tool(s) may also use this guide to identify functions that are recommended for specific laboratory environments. Research and development staff of different commercial laboratory informatics systems vendors may use the guide as a tool to evaluate, identify, and potentially improve the capabilities of their products. The vendors' sales staff may use the guide to represent functions of their laboratory informatics products to prospective customers in more generic and product neutral terms.

1.9 *Out of Scope*—This guide does not attempt to define the boundaries, as they continue to evolve, between the different types of laboratory informatics but rather focuses on the functionality that is provided by laboratory informatics as a whole.

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E1340 Guide for Rapid Prototyping of Information Systems
E2066 Guide for Validation of Laboratory Information Management Systems

2.2 *EPA Data Standard:*[3]
40 CFR 160 Code of Regulations, 54 FR 34067, August 17, 1989

2.3 *FDA Regulation:*[4]
FDA 21 CFR Part 11 Electronic Records, Electronic Signatures Final Rule, 62 Federal Register 13464, March 20, 1997

2.4 *GAMP:*[5]
GAMP 5 Good Automated Manufacturing Practice (GAMP) Guide for Validation of Automated Systems in Pharmaceutical Manufacture, ISPE, 2008

2.5 *ICH Standard:*[6]
ICH Quality Guideline Q9 Quality Risk Management

2.6 *IEEE Standards:*[7]
IEEE 829 1998 IEEE Standard for Software Test Documentation

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
[3] Available from United States Environmental Protection Agency (EPA), 1200 Pennsylvania Ave., NW, Washington, DC 20460, http://www.epa.gov.
[4] Available from Food and Drug Administration (FDA), 10903 New Hampshire Ave., Silver Spring, MD 20993-0002, http://www.fda.gov.
[5] Registered trademark of and available from International Society for Pharmaceutical Engineering (ISPE), 600 N. Westshore Blvd., Suite 900, Tampa, FL 33609, http://www.ispe.org.
[6] Available from International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH), ICH Secretariat, c/o IFPMA, 15 ch. Louis-Dunant, P.O. Box 195, 1211 Geneva 20, Switzerland, http://www.ich.org.
[7] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854, http://www.ieee.org.

IEEE 830 1998 IEEE Recommended Practice for Software Requirements Specifications
IEEE 1008 1987 IEEE Standard for Software Unit Testing
IEEE 1012 2004 IEEE Standard for Software Verification and Validation
IEEE 1028 1997 IEEE Standard for Software Reviews
IEEE 1063 2001 IEEE Standard for Software User Documentation

2.7 *ISO Standards:*[8]

ISO/IEC 12207 Information technology—Software life cycle processes
ISO/HL7 27932:2009 Data Exchange Standards—HL7 Clinical Document Architecture, Release 2

2.8 *NRC Standards:*[9]

FDA CFR Part 21 10 Code of Federal Regulations (CFR) Part 21.42 FR 28893, June 6, 1977
FDA CFR Part 50, Appendix B 10 Code of Federal Regulations (CFR) Part 50 Appendix B. 35 FR 10499, June 27, 1970, as amended at 36 FR 18301, Sept. 11, 1971; 40 FR 3210D, Jan. 20, 1975
FDA CFR Part 50, Appendix E 10 Code of Federal Regulations (CFR) Part 50 Appendix E. 45 FR 55410, Aug. 19, 1980, et sequentia as amended
FDA CFR Part 50, Appendix K 10 Code of Federal Regulations (CFR) Part 50 Appendix K. 21 FR 355, Jan. 19, 1956, unless otherwise noted

3. Terminology

3.1 This guide defines the majority of different terminology used in the laboratory informatics tools field. Users of this guide should request a terminology list from each vendor with a cross reference to the terms used in this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *chromatography data system, CDS, n*—computer system used to acquire, analyze, store, and report information from chromatographs.

3.2.2 *cloud computing, v*—term generally used to refer to software applications that are delivered as a software service through remote hosting using the public internet (public cloud) or within the users' network environment (private cloud).

3.2.2.1 *Discussion*—Essentially, the difference between cloud computing and a traditional application deployment is that the application users are not responsible for the installation and maintenance of the computing infrastructure and application software.

3.2.3 *corrective and preventative action, CAPA, n*—CAPA applications are used to collect information, analyze information, identify and investigate product and quality problems, and take appropriate and effective corrective or preventive or both action to prevent their recurrence.

3.2.3.1 *Discussion*—Verifying or validating corrective and preventive actions, communicating corrective and preventive action activities to responsible people, providing relevant information for management review and documenting these activities are essential in dealing effectively with product and quality problems, preventing their recurrence, and preventing or minimizing device failures.[10]

3.2.4 *data exchange standardization, n*—as defined by the International Organization for Standardization (ISO) in ISO/HL7 27932, the process of agreeing on standards, which represent the common language that allows the exchange of data between disparate data systems.

3.2.4.1 *Discussion*—The goals of standardization are to achieve comparability, compatibility, and interoperability between independent systems, to ensure compatibility of data for comparative statistical purposes, and to reduce duplication of effort and redundancies. A data standard often includes data elements, data element definitions, and such agreements as formats, message structures, vocabulary. In the context of this paper, a standard is a specification or requirement and is not synonymous with a policy, procedure, guideline, framework, technique, or best practice. Adopting standards has the potential to improve interoperability and reduce costs by facilitating the ability of networked laboratories to coordinate activities during public health incidents where surge capacity may be required (for example, national response and readiness). Adopting standards may reduce the costs of LIMS implementation and vendor/developer support.

3.2.5 *electronic document management system, EDMS, n*—used to store, catalog retrieve, view, and print digital documents.

3.2.5.1 *Discussion*—Modern EDMS applications typically provide the ability to manage a document throughout its lifecycle with functions including document initiation, multiple levels of review, version controls, security and archive of historical versions of documents.

3.2.6 *electronic laboratory notebook, ELN, n*—software program designed to replace paper laboratory notebooks. Defined by CENSA (Collaborative Electronic Notebook Systems Association) as "a system to create, store, retrieve, and share fully electronic records in ways that meet all legal, regulatory, technical and scientific requirements."

3.2.6.1 *Discussion*—Laboratory notebooks in general are used by scientists, engineers, and technicians to document research, experiments, and procedures performed in a laboratory. A laboratory notebook is often maintained to be a legal document and may be used in a court of law as evidence. Similar to an inventor's notebook, the laboratory notebook is also often referred to in patent prosecution and intellectual property litigation.

3.2.7 *enterprise resource planning, ERP, n*—ERP system integrates different types of data such as inventory levels, product orders, accounting, manufacturing capacity, inspection results, and customer relationship management information from organizations within an enterprise (company) to facilitate the flow of information between various business functions across a company as well as with outside business partners.

[8] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[9] Available from U. S. Nuclear Regulatory Commission (NRC), One White Flint North, 11555 Rockville Pk., Rockville, MD 20852-2738, http://www.nrc.gov.

[10] For additional information, visit http://www.fda.gov/ICECI/Inspections/InspectionGuides/ucm170612.htm#page1.

3.2.8 *good automated manufacturing practice forum, GAMP Forum, n*—a volunteer group under the auspices of the International Society of Pharmaceutical Engineering (ISPE) for writing guidance for the validation of computerized systems used in the regulated portions of the pharmaceutical and allied industries. It is specifically designed to aid suppliers and users in the pharmaceutical industry.

3.2.9 *integration broker, n*—messaging application that can receive or extract data from a source system at the appropriate time, transform the data, and route the reformatted data to the target node.

3.2.9.1 *Discussion*—An integration broker application can also provide a repository for archiving, searching, and retrieving these messages.

3.2.10 *laboratory information system, LIS, n*—class of application software that supports clinical laboratories by helping technologists manage the quality and integrity of test samples; departmental workflow functions, result review processes, reporting of finalized results, interpretations, and diagnosis.

3.2.10.1 *Discussion*—These systems often interface with instruments and other information systems such as hospital information systems (HIS). A LIS is a highly configurable application and often includes laboratory-specific electronic medical records; direct clinician access via secure web connections; billing modules for laboratories performing commercial testing; sophisticated interface engines for routing orders and results to external systems; and on-board image archival systems for pathology images. Patient confidentiality and HIPAA requirements define unique security functionality for a LIS. The College of American Pathologists (CAP) publishes LIS product guides[11] that list current LIS in the market.

3.2.11 *laboratory execution system, LES, n*—computer system used in the laboratory at the analyst work level to aid in step enforcement for laboratory test method execution.

3.2.11.1 *Discussion*—Laboratory execution systems (LES) focus on step execution of defined laboratory test methods. The LES are typically used in quality control laboratories that have defined test methods. The functionality of LES and LIMS overlap in the areas of result entry, instrument integration and specification flagging. Deployment options include LES and LIMS systems deployed as an integrated solution, LIMS only or LES only (for limited functions).

3.2.12 *laboratory informatics, n*—term used to describe the specialized application of information technology aimed at optimizing laboratory operations and it is a collection of informatics tools utilized within laboratory environments to collect, store, process, analyze, report, and archive data and information from the laboratory and supporting processes.

3.2.12.1 *Discussion*—Laboratory informatics includes the integration of systems, the electronic delivery of results to customers, and the supporting systems including training and policies. Examples of laboratory informatics include: Laboratory Information Management Systems (LIMS), Electronic Laboratory Notebooks (ELNs), Chromatography Data Systems (CDS) and Scientific Data Management Systems (SDMS).

[11] For additional information, visit http://www.captodayonline.com/productguides/software-systems.html

3.2.13 *laboratory informatics tools configuration, n*—refers to the process of changing the functions of any of the laboratory informatics tools to match the business process used in a particular laboratory. It does not involve the use of writing software code either via a recognized software language or a language provided by the informatics application supplier. This is a GAMP 4 software category.

3.2.13.1 *Discussion*—It typically involves using an interface provided by the vendor to enter information that describes the types of samples, analytical methods, specifications, and so forth used in the laboratory.

3.2.14 *laboratory informatics tools customization, n*—refers to the process of changing the functions of any of the laboratory informatics tools to match the business process used in a particular laboratory. It involves the writing software code either via a recognized software language or a language provided by the informatics application supplier. This is a GAMP 5 software category.

3.2.14.1 *Discussion*—It typically involves adding tables, modifying table structures and writing code or programs to alter the behavior of any of the laboratory informatics tools.

3.2.15 *laboratory information management system, LIMS, n—(1)* computer application(s) software and hardware that can acquire, analyze, report, and manage data and information in the laboratory; *(2)* computer software that is used in the laboratory for the management of samples, test results, laboratory users, instruments, standards, and other laboratory functions such as invoicing, plate management, product/material stability programs, and work flow automation; and *(3)* a class of application software which handles storing and managing of information generated by laboratory processes.

3.2.15.1 *Discussion*—These systems are used to manage laboratory processes including defining master data, sample management and chain of custody, work assignment, instrument and equipment management, standard and reagent management, scheduled sample collection and testing, result entry, result review, reporting, trending and business rule enforcement. These systems interface with laboratory instruments (for example, chromatography data systems (CDS), and other information systems such enterprise resource planning (ERP), manufacturing execution systems (MES), or health care based laboratory information systems (LIS)). A LIMS is a highly flexible application, which can be configured or customized to facilitate a wide variety of laboratory workflow models.

3.2.16 *lean laboratory, n*—set of management and organizational processes derived from lean manufacturing and the Toyota Production System (TPS) and the goal of a lean laboratory is to use less effort, fewer resources, and less time to test incoming samples.

3.2.17 *mapping tools, n*—graphical data mapping, conversion, and integration applications that map data between any combination of XML, database, flat file, EDI, Excel (OOXML), XBRL, and/or web service, then transforms data or autogenerates data integration code for the execution of recurrent conversions.

3.2.18 *metadata, n—(1)* data about data and *(2)* information that describes another set of data.

3.2.18.1 *Discussion*—Metadata in any laboratory informatics tools context typically includes all data that supports a test result that is recorded in this tool. Examples include for a pH test, a pH result can be supported by metadata including what instrument was used, what is the calibration date of the instrument, what standard buffer solutions (reagents) were used to calibrate the pH probe sensor, the expiration dates for the standard solutions and the temperature of the solution at time of measurement.

3.2.19 *sample registration, n*—process of recording incoming sample information in a given laboratory informatics tool.

3.2.20 *scientific data management system, SDMS, n*—used to capture, centrally store, catalog, and manage data generated in a laboratory environment.

3.2.20.1 *Discussion*—These data are then available for reuse and integration with other laboratory informatics systems. An example of an SDMS is an electronic repository for reports from laboratory informatics systems.

3.2.21 *spectroscopic data systems, n*—computer systems used to collect, process, visualize, interpret, store, and report information from spectroscopic instruments.

4. Significance and Use

4.1 *Relevance*—This guide is intended to educate those in the intended audience on many aspects of laboratory informatics. Specifically, the guide may:

4.1.1 Help educate new users of laboratory informatics;

4.1.2 Help educate general audiences in laboratories and other organizations that use laboratory informatics;

4.1.3 Help educate instrument manufactures and producers of other commonly interfaced systems;

4.1.4 Provide standard terminology that can be used by laboratory informatics vendors and end users;

4.1.5 Establish a minimum set of requirements for primary laboratory informatics functions;

4.1.6 Provide guidance on the tasks performed and documentation created in the specification, evaluation, cost justification, implementation, project management, training, and documentation of laboratory informatics; and

4.1.7 Provide high-level guidance for the integration of laboratory informatics.

4.2 *How Used*—This guide is intended to be used by all stakeholders involved in any aspect of laboratory informatics implementation, use or maintenance.

4.2.1 It is intended to be used throughout the laboratory informatics life cycle by individuals or groups responsible for laboratory informatics including specification, build/configuration, validation, use, upgrades, retirement/decommissioning.

4.2.2 It is also intended to provide an example of a laboratory informatics functions checklist.

5. Laboratory Informatics Concept Model—Graphic Picture of Systems and Functionality

5.1 *Laboratory Informatics Systems Evolution*—Fig. 1 shows a timeline for the development of software products designed to meet the needs of the laboratory community. Over time additional software tools entered the laboratory and existing software products added functionality. The expanding breadth of software tools available illustrates the increased functionality and complexity of laboratory informatics solutions. The laboratory informatics solutions/tools illustrated in this figure are examples and do not imply these are the only tools available.

5.2 *Laboratory Informatics Systems Integration Concept Model*—Laboratory informatics systems, the possible overlaps between them, and their potential integration with business and enterprise computer systems both within organizations and with customers of laboratory information are illustrated in Fig. 2.

5.3 *Laboratory Informatics Functions*—Laboratory informatics core and extended functions are illustrated in Fig. 3. The figure defines:

5.3.1 Core laboratory functions are described by items listed in boxes labeled with C-x;

5.3.2 Extended laboratory functions are described by items listed in boxes labeled with E-x;

5.3.3 Functions related to system configuration, administration and validation are shown with boxes labeled with S-x; and

5.3.4 Document support functions are described in boxes labeled with D-x.

5.4 *Laboratory Informatics Systems Life Cycle Phases*—Fig. 4 defines the high-level system life cycle phases of: *(1)* initial system implementation, *(2)* system operations, and *(3)* system maintenance. Each of these primary phases is further decomposed into primary functions. The numbering scheme used matches the definitions in Fig. 3 and also ties to the requirements section located in Appendix X1.

5.5 *Laboratory Informatics Additional Functional Requirements by Laboratory Type*—All analytical laboratories require a basic work flow including sample or experiment registration, assignment of tests, entry of results, review and approval and reporting. Laboratories in various industries may require additional functionality to meet additional workflow requirements. An environmental laboratory, for example, may require tracking of sample containers, processing of samples in batches with control samples, instrument integration, multiple levels of review, and specific reporting requirements. Some laboratory informatics systems vendors gear their solutions towards a particular industry segment, while others attempt to meet the needs of many laboratory types. Fig. 5 illustrates some of the additional functions that may be required to address the needs of particular laboratory types. The functions illustrated are over and above the basic laboratory workflow and are by no means an exhaustive list, but merely examples of possible additional functionalities.

6. Laboratory Informatics Workflow and Sample Life Cycle

6.1 *Laboratory Informatics Workflow Introduction*—The laboratory informatics workflow model (see Fig. 6) provides a generic representation of the process flow in a typical analytical laboratory. The purpose of the work flow diagram is to

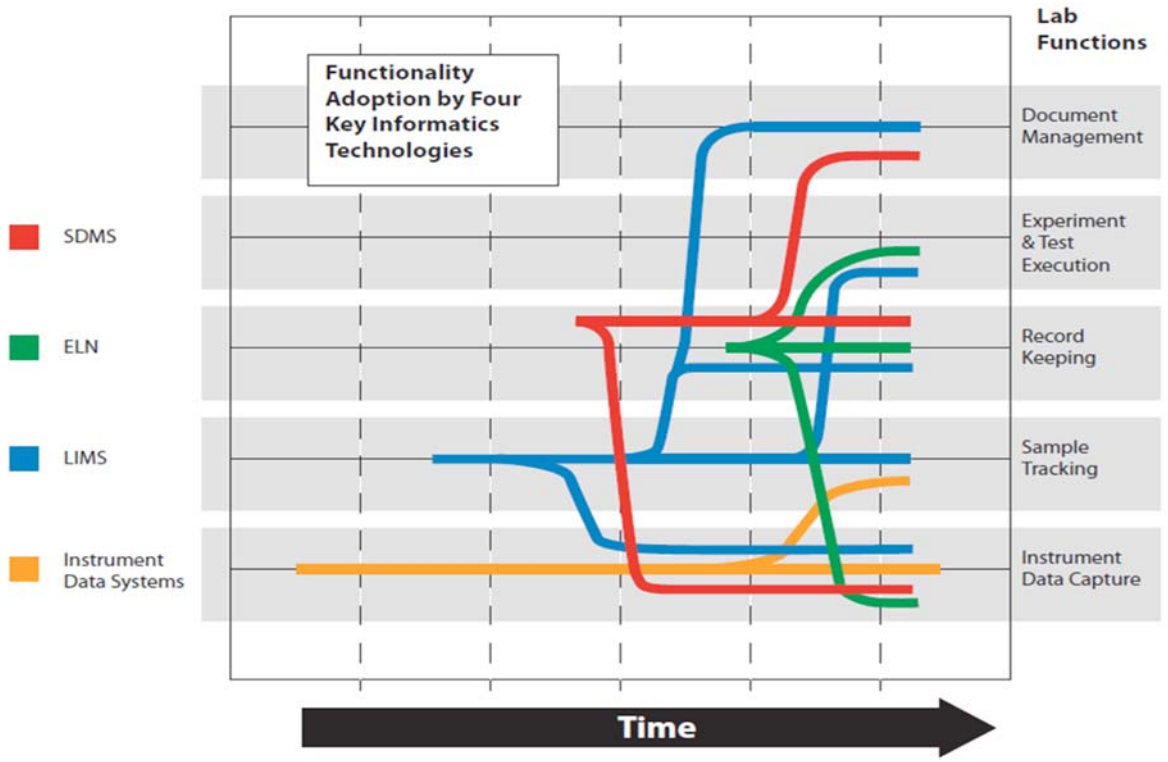


FIG. 1 Laboratory Informatics Systems Evolution

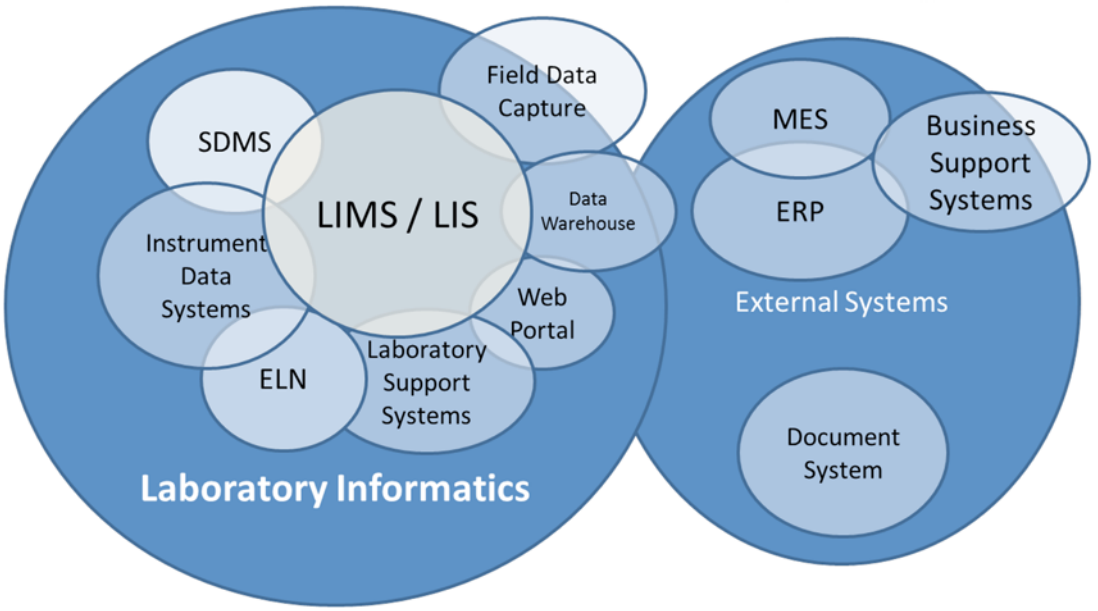


FIG. 2 Laboratory Informatics Systems Integration Concept Model

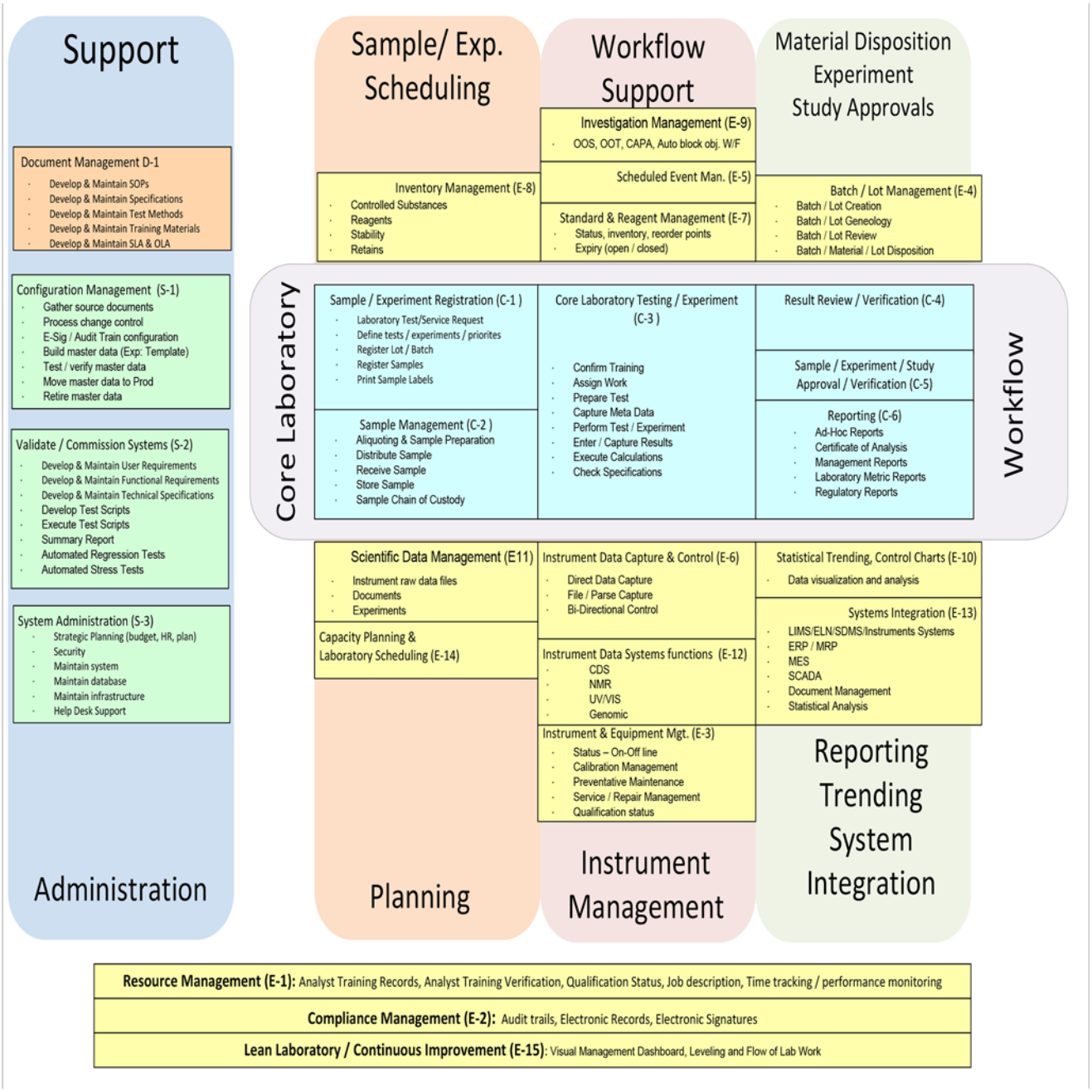


FIG. 3 Laboratory Informatics Functions

elucidate the laboratory informatics functions and interaction points with typical laboratory work processes (that is, processing of samples, analysis, and reporting). Specific laboratory workflow requirements and test definition may vary widely from one laboratory to another, as well as from one industry to another. However, before implementing a laboratory informatics solution, care should be taken to completely define and document the unique requirements and data model for the laboratory in question. To achieve a successful deployment and use of a laboratory informatics solution, it shall be properly configured before deployment. The relatively stable information about personnel, customers, tests, reports, and the like, shall be entered into the static data. Once configured, the laboratory informatics solution is able to facilitate the sample lifecycle process. The boundaries of the laboratory informatics solution should be established during the data model design phase.

6.2 *Laboratory Informatics Data Model*—Defining the correct data model for the laboratory is essential to a successful laboratory informatics implementation and deployment. Many laboratories opt for data models that are procedure centric (that is, test methods are defined from approved external procedures and SOPs) where the requestor selects the appropriate laboratory informatics methods based on a knowledge of which procedures are appropriate for the sample in question. This

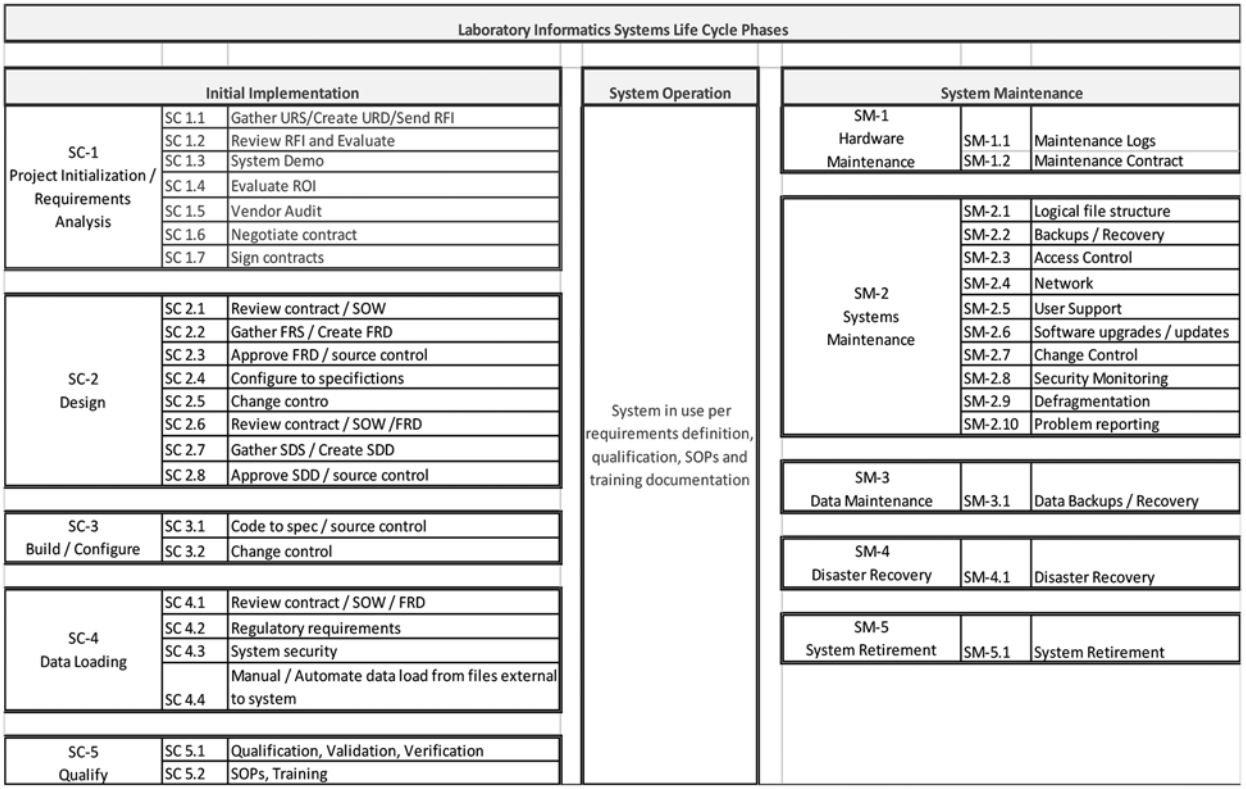


FIG. 4 Laboratory Informatics Systems Life Cycle Phases

model relies on the experience of the user and has great flexibility for the R&D laboratory or laboratories where a wide variety of samples are submitted. Other models are sample or product specific (that is, a suite of "approved" tests are bundled together and typically always applied to one sample type), as is typically the case for a QA laboratory in charge of product release. This model removes the dependency upon the requestor to select the appropriate tests when submitting the sample for analysis and improve compliance to testing plans.

6.2.1 *Types of Data*—The technology used by a laboratory informatics solution varies with each vendor and platform. However, laboratory informatics databases are typically divided into two broad areas: *(1)* static data where descriptive information is defined (for example, users, locations, profiles, tests, calculations, specifications, and related information; commonly found in "look up/reference/dictionary" tables) and *(2)* dynamic data where sample and result/determination information is stored as samples are logged and results are entered. The terms static and dynamic represent a general characterization of laboratory informatics data, reflecting the frequency of change. The laboratory informatics implementation team shall assess the current laboratory information organization and workflow in order to match the two database areas (static and dynamic) to the information/data collected, generated or required by the laboratory in order to conduct their laboratory processes, whether that be in processing samples or in general laboratory experiments.

6.2.2 *Statuses*—Laboratory informatics solutions are generally capable of maintaining information on the status of various items, for example, but not limited to: experiments, samples, individual tests/determinations, comparison of results to specifications, verification of results, approval of samples/orders, workflows, and much more. Status values provide the insight with the laboratory informatics solution to track the item's progress in its workflow (that is, active, complete, reviewed, and so forth) and may provide context on the evaluated result (that is, pass/fail). Other status information may be updated as each laboratory informatics transaction takes place. Individual functions/workflows may be configured to have an associated status value. Examples of sample/order statuses include, but are not limited to (and should be reflective of the laboratory's unique workflow): unavailable, available, received in the laboratory, testing in progress, suspended, complete, approved, and rejected. Examples of test/determination statuses include: available, active, complete, approved, out of specification.

6.2.3 *Data Load and Migration*—A laboratory informatics solution is capable of maintaining information for a broad range of business and laboratory data required for the effective operation of the laboratory. Laboratory informatics contains data that not only reflects the current operation state of the laboratory but also historical information on past performance and events. When implementing a laboratory informatics solution in a previously manual environment or replacing an outdated electronic version, it shall be determined how much and of what type (if any) historical data should be carried forward (that is, loaded, "migrated," or re-entered) into the new laboratory informatics solution to provide the base configuration. Static data are generally always loaded into the laboratory informatics solution as part of the deployment lifecycle. The

Additional Functions Required by Laboratory Types		Laboratory Functional Area					
		Sample / Experiment Management	**Lab Testing**	**Review, Verification Approval**	**System Integration**	**Reporting and Trending**	**Other Functions**
Laboratory Type	**General Laboratories**	Chain of custody	Batch Processing of Samples including QA		ELN, SDMS, instrument integration	Electronic Reporting of QC Results	
	Environmental	Container management, Chain of custody, regulatory compliance - significant auxiliary data	Batch Processing of Samples including QA	Multiple levels of review and approval	GIS integration	Electronic Reporting of QC Results by batch	Method QA/QC, Calculation validation, electronic data delivery
	Public Health Sector- (clinical microbiology and chemical)	Chain of custody, electronic test ordering, Emergency response, public health surveillance	Batch Processing of Samples including QA, agent regulations	Multiple levels of review and approval, CLIA certification	Emphasis on surveillance at multiple state and federal levels	Electronic Reporting multiple data formats, vocabulary, and secure transport	Clinical and non-clinical, sample centric and patient centric
	Life Sciences	Controlled substances Stability samples	Uniformity Calculations Product Specifications	Multiple levels of review and approval	ERP integration	SPC and Process variability analysis	Instrument maintenanc e and calibration tracking
	Food and Beverage	Lot geneology	Product Specifications		MES and ERP integration	SPC and Process variability analysis	Exception Reporting
	Heavy Industry	Automatic scheduling, Lot Management	Product Specifications		Process Control / PM integration	SPC and Process variability analysis	
	R&D	Experiment sharing	Method versioning		ELN, SDMS, instrument integration	Experiment Conclusions, Technical Reports	Expanded Search capability
	Medical Laboratory	Embedded LIS Standalone LIS Niche LIS Patient centric			interface engines to external systems	Unique functions Diagnostic and Surveillance	electronic medical records; direct clinician access, billing modules

FIG. 5 Laboratory Informatics Additional Functional Requirements by Laboratory Type

decision on how to deal with historical dynamic data should be evaluated on the basis of risk. Appropriate strategies for dealing with this data include migration, preservation and archival. In cases in which a new solution is replacing an existing laboratory informatics solution, it may be possible to migrate data from the source laboratory informatics solution to the new target deployment. Migration of data needs to be carefully analyzed and planned. The plan should include processes to verify that the data are successfully migrated to the new database.

6.3 *Sample Management and Life Cycle:*

6.3.1 *Sample Registration*—Sample registration may precede or follow physical sample collection. The laboratory informatics sample registration function should be a simple, straightforward process with an intuitive and efficient user interface. The initiation of a request for testing/sampling generally starts the sample workflow process. Sample requests may include manual forms, electronic forms, phone requests, web requests, process-driven requests, time or calendar-based requests, ad-hoc requests, and system-generated requests. Information obtained from the sample request should include biographical, client, requested test(s), and safety information.

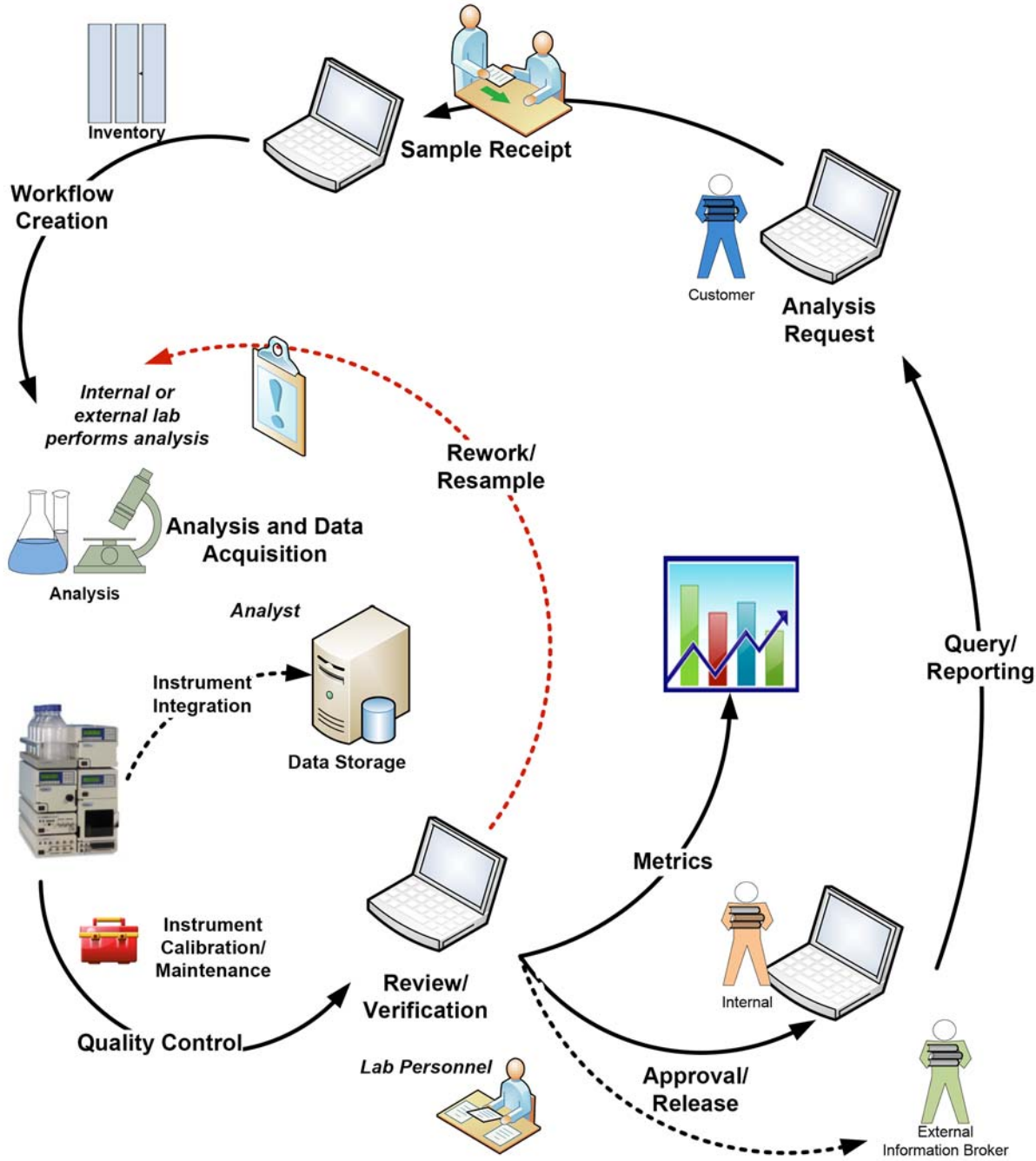


FIG. 6 Laboratory Informatics Workflow Model

Some laboratory informatics solutions allow the laboratory to pre-log or post-log samples or the client to pre-log samples through a web portal.

6.3.1.1 *Store/Retrieve Sample*—An often overlooked benefit of utilizing a laboratory informatics solution is the ability to manage inventories for reference samples, laboratories reagents, standards, QC samples, time-based samples (shelf-life stability), and laboratory equipment/instruments, in addition to normal samples. Inventory functions may provide critical business information with respect to resource and consumables management as well. This could include such information as expiration dates, vendor information, restock quantities, as well as, in the case of instruments; calibration status, maintenance history, and so forth.

6.3.2 *Sample Identification*—The laboratory informatics solution should assign a unique number to each sample registered (that is, submitted for testing). The unique number can be a system generated sequential integer or a user-defined sequence. Multiple samples, submitted together for registration should be logically "linked" in the laboratory informatics solution (for example, all samples for a particular lot). The system will normally provide functionality to capture descriptive information about the sample(s) such as who submitted the sample(s), costs, sample description, and what tests are to be performed

on the sample. Other information may also be important, such as the priority of the tests, what level of accuracy and precision of testing needed, what hazards the sample might present to the laboratory personnel, what approximate levels of components are expected, and what should be done with the sample when analysis is complete.

6.3.2.1 A confirmation report is often issued (sometimes emailed) to assure requestors that the system accepted the sample request and may accompany the physical samples as they are delivered to the testing laboratory. Often, laboratory informatics solution statuses are updated for the sample/order and may be used to record the fact that an order was made (for keeping operational metrics) and when it was made so the system can track the time intervals for the remaining steps of the process. This will also allow laboratory management to determine turnaround time, sample status and various overdue conditions.

6.3.3 *Sample Collection*—Sample collection may be a manual, automated, or robotic process. The sample collection logistics may become more efficient by having the laboratory informatics solution print collection lists and generate labels (for example, bar codes) for the sample containers. Sample collection can precede or follow sample registration as defined by the laboratory's workflow. The laboratory informatics solution can provide information on how to collect samples, specific sample plans, container and preservation requirements, safety [Material Safety Data Sheets (MSDS)] information, sample storage requirements, and sample routing information. Chain of custody for samples is often tracked by the laboratory informatics solution, generally for location and status information. Chain-of-custody may be required to provide documented evidence of control and traceability of sample containers and their contents. Examples of situations where chain-of-custody requirements may be required include handling of controlled substances, pieces of evidence (forensic) supporting legal court cases, or radioactive materials. It is important to note, that this functionality may not have all legal chain of custody requirements for specified sample types as defined by governmental or law enforcement agencies. The implementation team should review these requirements carefully during the planning/implementation phase.

6.3.4 *Sample Receipt*—The physical receipt of samples in the laboratory may be recorded in the system and may also include initial sample checking and labeling. Sample orders or groups of samples may be reviewed against customer or project sampling requirements. Additional information such as the number of samples received and the arrival time may be recorded and the status of samples may be updated for the sample/order from logged to received. Where collection lists are used, a "missed sample" report should be used to indicate those samples that were not received as expected.

6.3.4.1 The laboratory informatics solution may be configured to specify the aliquot requirements for a sample based on the tests to be performed on it. Upon sample receipt, any issues, such as an unexpected color or physical state, may be noted and recorded within the sample record. The laboratory informatics solution should be flexible enough to allow preliminary sample treatment, such as addition of a preservative, to be performed and documented.

6.3.5 *Sample Distribution*—Distribution processes often include important laboratory informatics solution functions such as work lists, resource allocation, sample routing and custody.

6.3.5.1 The laboratory informatics solution should provide a listing of all the tests that shall be performed, the amount of material required, and where samples are to be sent. The date and time of sample distribution is important since it designates when the sample becomes available to the various laboratory workstations for analysis. Sample status may be updated to indicate samples are available for analysis at this time as well.

6.3.6 *Work Assignment*—Once samples arrive in the laboratory, the work shall be scheduled and allocated against available resources, people, and/or equipment. Resource availability and management may be handled through the laboratory informatics solution, if configured to capture this information. By utilizing the laboratory informatics solution appropriately, resources may be forecast, allocated, and tracked to improve the overall efficiency of the laboratory. The laboratory informatics solution may also be configured, in some instances, to group automatically samples into runs or sequences and schedule work (tests) for each sample/order, as well as be configured to allow authorized users to perform these functions manually.

6.3.7 *Disposal of Samples*—The proper documentation of sample disposal following analysis is an important responsibility of the laboratory. The laboratory informatics solution may be used to track final sample disposition.

6.4 *Analysis:*

6.4.1 *Sample Preparation*—Most samples require some preparation before analysis. The laboratory informatics solution may be configured to provide sample preparation directions for these preliminary processing and sample preparation steps, however this information may also be available in the form of standard operating procedures, technical documents, or work instructions stored externally to the laboratory informatics solution. In addition, it may be configured to capture who and when the sample preparation was completed.

6.4.2 *Sample Analysis*—Analysis activities will vary from laboratory to laboratory. Depending upon the laboratory's requirements and data model, much of the information gathered during this phase, other than the actual result data, may be recorded in a hardcopy laboratory notebook, or captured within another laboratory informatics solution as sample or method attributes. In general however, the analysis phase contains the following subparts:

6.4.3 *Perform Test*—Test results/determinations are the main output of the analysis process. Intermediate and final test results for the samples, standards and their associated QC samples may be reported out in hard copy, electronic formats, or both. In addition, the measurement process may produce values for additional internal blanks, standards, and instrument self-checks. The definition of what is the laboratory's "raw data" and what needs to be retained for legal evidence may be defined differently for each client or agency involved and should be a fundamental part of the data model design process.

6.4.3.1 *Re-Test Loop*—Retests can be initiated at multiple points in the laboratory informatics solution workflow. A re-test is defined as one or more additional determinations on the original sample/order container. These retests would normally be ordered if a given test was suspected to fail for reasons that may include failed quality control parameters, instrument malfunction or technical judgment. The laboratory informatics solution should document each retest along with an appropriate justification.

6.4.3.2 *Re-Sample Loop*—Re-samples can also be initiated at multiple points in the laboratory informatics solution workflow. A re-sample is defined as one or more additional samples. The laboratory informatics solution needs to establish forward and backward links to samples that are added by way of the re-sample loop. These re-samples would normally be ordered if a given sample was suspected to fail for reasons that may include where insufficient sample was available for a retest, technician judgment that the original sample was not appropriate for the test performed, or to confirm a test failure.

6.4.4 *Data Capture*—The results of the analysis should be captured within the laboratory informatics solution. While this may be a manual process, the true power of laboratory informatics lies in automating data transfer. This can involve automated capture of instrument data files, printable reports, data from simple devices, and automatic extraction of information from one part of the laboratory informatics implementation and transfer into another one. The amount and type of supporting data to include with the result data, should be carefully evaluated and defined during the data model design. When a test result/determination is captured, the statuses of the sample/order and result determination should be updated. The associated date/time records should also be captured so that they can keep statistics of work accomplished and track the progress of each test order. The laboratory informatics solution should have electronic audit trails that record biographical information about each transaction.

6.4.4.1 Direct instrument integration with the laboratory informatics solution is critical to fully realizing the business benefits of the solution. In cases in which instruments are bidirectionally interfaced to laboratory informatics solutions, the sequence of unknown samples and control standards may be transferred to the instrument to streamline instrument setup before analysis. The sequence should include information such as sample ID, analyst ID, analysis date/time, and/or other pertinent information.

6.5 *Analysis Review:*

6.5.1 *Test Result Review and Interpretation*—A laboratory should require that each test result undergo one or more levels of documented review and interpretation. The laboratory informatics solution can be configured to document at multiple levels of review. The original sample result would typically be reviewed and interpreted by the primary analyst for any anomalies associated with the performance of the test method. This review can be documented in the laboratory informatics solution. Laboratories often require that results be reviewed by a second qualified person (this is industry specific and dependent on regulatory requirements) to ensure that the tests were properly executed, documented, entered, and interpreted.

6.5.1.1 To help in this process, the laboratory informatics solution may indicate the unusual or out-of-range results as flagged for further evaluation. If normal values are known for the substance being tested, they can be displayed. Results outside of normal can be highlighted or displayed separately for closer review. The laboratory informatics solution can enforce laboratory SOPs that require the reviewer to be a different person from the tester. Corrections or changes to laboratory informatics solution data made during the verification step should be audit trailed and require authorization with change comment. Audit trails should contain original data and all changes to the result record including date/time of change, who made the change, and the reason for the change. Electronic signatures may be used to confirm changes in status to the laboratory informatics solution records if the regulations or guidelines require this. Management may need to know when results are verified—another milestone in the progress of a test/sample/order. Not all laboratory informatics solution implementations require audit trails. The laboratory informatics solution implementation team needs to determine whether audit trails are important, what information should be audited, and whether reasons for changes should be recorded during the data model design phase.

6.6 *Sample Disposition:*

6.6.1 A laboratory generally requires that samples undergo a documented review/approval process to disposition the sample to indicate that it has been evaluated against established criteria. The laboratory informatics solution can be configured to document the review/approval process. Since the laboratory exists to generate information for the parent/client organization, the laboratory may organize and configure results to make interpretation and decision-making easier. Analysis is frequently done to confirm quality or properties of a material. In this case, material specifications may be entered into the laboratory informatics solution so that results can be checked against acceptable values to determine whether the sample meets/does not meet specifications. Electronic signatures may be used to document the sample review/approval process and update the sample status in the laboratory informatics solution records. In addition, certain industries/regulations prohibit final sample approval by the analyst who performed the test. Restrictions of this nature need to be identified during the implementation design phase so that the laboratory informatics solution configuration will support the constraint.

6.6.2 The output of the review/approval process is verified data and may be in the form of data reports, Certificates of Analysis (COA), or direct process control actions. Often, the interpretation function coincides with the reporting process. In many laboratory informatics solutions, data are interpreted in a reported format either in electronic or paper forms.

6.6.3 Result data itself can undergo a separate evaluation and disposition process from the sample. In some industries and research organizations, the pass/fail status (or approved/rejected, that is, multiple terminology exists) of an individual result data point is captured, yet the overall sample is approved because the science generating the result value is sound. This is a key element that the implementation team needs to incorporate into the data model design.

6.7 *Reporting:*

6.7.1 Following verification, data reported to the customer may include test results (including quality control data), auxiliary data such as sample demographics, and accompanying pass through data and is not "generated" by the laboratory, other data necessary for data evaluation such as sample characteristics such pH or temperature. This can take a variety of forms, including hardcopy reports, electronic data deliverables, and web-based systems. The report generators within a given laboratory informatics solution need to be flexible to accommodate the different reporting needs of individual clients. The laboratory informatics solution vendors provide basic formats for the most common hardcopy and electronic reporting formats. Conventional Certificates of Analysis (COA) are commonly supplied as an example of a hardcopy report. Many clients are now relying on the use of various electronic formats that support the transfer of data from the laboratory informatics solution database to the client's database using electronic transfer formats such as XML-based. In some cases, the data is maintained in the data warehouse and accessed on an as needed basis, rather than actively sending reports.

6.7.2 Reports can include summaries for internal laboratory use by management. Reports on standard and non-standard samples entering the laboratory can be useful for organizing the laboratory into routine and advanced characterization groups. Reports can also include the priority of a sample's registration to understand the resource needs of the laboratory. Management functions are told when the reports are issued, because this marks the end of the turn-around time. Laboratory informatics statuses are updated for the sample/order. By collecting statistics and time-stamps at various points in the process, reports can be prepared for laboratory managers. Number of samples processed at each workstation by shift, day of week, and hour of day can be prepared. This can help identify peak demands, roadblocks, and other problems and provides good documentation to justify new instruments or personnel. Instrument utilization time records help in understanding the instruments operated/day in hours, test method utilized maximum, and types of samples received and this is useful in developing test costs for standard and nonstandard analyses. Turnaround times document the laboratory's responsiveness to customer needs. Overdue results and work remaining in the system help managers to determine how well the laboratory is responding to current demands. Personnel time accounting can be tracked by the time each sample is at each workstation. This can be used to bill by project, monitor personnel performance, and share headcounts among the projects. The number of tests done can be used to estimate the consumption of reagents and supplies. Instrument calibration and maintenance records can be maintained and reported by the laboratory informatics solution. Audit reports by sample can indicate the processing time for a test/method in an instrument and thus laboratory productivity. Report on number of samples retested and resampled can give an idea of the training needs of the personnel and other workflow problems.

6.7.3 Quality control reports can also be prepared for internal laboratory use. Statistical reports can be generated to evaluate the performance of a given method within the laboratory. Control charts can be generated based on analysis of specific QC samples. Some laboratory customers require that these statistical ranges also be reported to them and by appropriately configuring the laboratory informatics solution, reporting may be simplified. Reports on out of specification results and CAPA reports are useful for production, QC, FDA, ISO, and compliant laboratory environments.

7. Laboratory Informatics Infrastructure, Integration and Interfaces

7.1 *Hardware Infrastructure:*

7.1.1 *General Requirements*—The hardware infrastructure is an important factor in the deployment of all laboratory informatics solutions. This platform includes the computing requirements (processor capability, memory, disk space) and the network requirements (bandwidth, security, instrument connectivity, LAN/WAN). The architecture of the hardware platform should be driven by the requirements of the business it supports. Acquisition and deployment of the actual hardware devices can be staged to match the software implementation schedule.

7.1.2 *Key Considerations*—Most laboratories no longer have complete control over essential informatics activities. To increase efficiencies and cost-savings, organizations are moving to either consolidated (aka "centralized") information technology (IT) services or shared services (a hybrid model with aspects of centralization and decentralization). Consolidated or shared IT services have the potential to reduce costs and achieve certain benefits, but they also pose new challenges for laboratory leaders. This IT consolidation is driven by advances in technology such as redundant disk arrays permitting the central storage and management of hundreds of terabytes of information at relatively low cost; server virtualization products enabling a single computer to run multiple software products, each designed for a different operating system; and advances in network communications and fiber optics that increase wide area network speed and reliability. These advances often provide greater functionality at reduced costs. When evaluating the hardware infrastructure, the following capabilities and features should be considered:

7.1.2.1 *Concurrent Users*—The number of laboratory informatics solution users and users of other applications, if computing resources are shared, is important especially when considering system performance at peak times of the day.

7.1.2.2 *Number of Records Created per Year*—The number of samples, average number of tests per specimen, and the amount of data generated during the testing is important in estimating the system resource requirements.

7.1.2.3 *Online Storage*—This includes the number of records to be maintained on-line as well as the data generated during testing.

7.1.2.4 *Archival Storage*—Both the amount of storage required and the length of storage are important factors.

7.1.2.5 *Number and Type of Reports Required*—The number of reports to be generated during a work day, the location of the

printers and the types for printers [one-dimensional (1-D) or two-dimensional (2-D) barcode label printers/scanners, special paper/label requirements].

7.1.2.6 *Instrument Connectivity*—The location of the instruments, bandwidth requirements, OS requirements, security issues, separate or shared corporate network should be defined.

7.1.2.7 *Network Bandwidth*—Latency and network speed can be the limiting factors in overall system performance.

7.1.2.8 *Application Load Balancing*—The software architecture determines how well the laboratory informatics solution can be balanced over multiple processors. The ability to add hardware components (hardware scalability) to meet demands is important.

7.1.2.9 *Network Security*—Systems accessible from the public internet need hardware to support the appropriate level of security. Instruments connected to the network shall also meet security requirements.

7.1.2.10 *Distributed Computing*—Global application deployment requires support for computing and connectivity across multiple regions and continents. Systems can use a single or multiple database instances.

7.1.2.11 *Resource Needs of Non-Laboratory Informatics Solutions*—In a shared computing environment the resource requirements for non-laboratory informatics solutions (business applications, manufacturing applications) are factors in system performance.

7.1.2.12 *Data Backup Requirements*—The criticality of the data and the difficulty in recovering lost data should be determined. Hardware options such as server mirroring or other data replication approaches are considerations.

7.2 *Database Recommendations:*

7.2.1 *General Requirements*—The database component of the laboratory informatics system requires the greatest level of resilience due to the ever-increasing demands of information exchange between the laboratory and the enterprise. The laboratory informatics system should be based on a commercial database management system that is reliable, effective and supported. Commercial relational database management systems can be organized, configured, and tuned to meet a wide variety of usage and performance scenarios.

7.2.2 *Key Considerations*—The following features should be considered as part of the database platform evaluation:

7.2.2.1 *Standardization*—The database should allow an application or the database administration personnel to interact with the database based on industry best practices and common standards for relational database systems, such as the use of structured query language (SQL) for database queries. Ideally the database platform should also conform to the database platforms and standards currently in place in your enterprise.

7.2.2.2 *Core Design Flexibility*—The database schema design provided by the laboratory informatics vendor should be well documented and sufficiently flexible to accommodate common laboratory informatics solution administration and configuration tasks, such as the maintenance of users, modification of workflows, reference information in lookup tables, and the potential addition of user-defined fields. The design should preserve the referential integrity of information in the database, that is, addition, deletion or updating of data in one area should be dependent upon the impact of data that it refers to. All data types used in the workflow of the laboratory should be accommodated by the database, including a full range of numeric, date/time and text data types. Other data types required may include the ability for data types to support the storage of images, multimedia, XML and other proprietary data files.

7.2.2.3 *Extended Design Flexibility*—The database should support the ability to modify the database structure as needed, including adding/modifying fields, indexes, relationships, and tables. However, careful consideration should be given to the impact on laboratory informatics solution functionality before making these changes, especially where alignment across multiple locations to minimize maintenance costs is desired. The laboratory informatics vendor should provide guidance on how to achieve database modifications in a controlled manner.

7.2.2.4 *Data Replication*—The function of data replication is critical to protecting and maintaining information in the laboratory informatics system. Laboratories that utilize electronic records should ensure the protection of information captured within the system. Typical snap shot or incremental backup processes run nightly but provide limited protection between backup intervals. Data replication tools within the database layer (and sometimes between the storage layers [storage area networks (SANs)] provide added protection against data loss by replicating all transactions between data centers or remote servers.

7.2.2.5 *Multiple Environments (development, quality (test) and production platforms)*—The database platform should support the ability for multiple environments (copies) of the database and migration tools to move objects between environments. Typical implementations include a development environment for code/configuration development, a quality environment for formal testing and master data building, and a production environment for production information. The database environments include application development components for data administration, application customization, and integration. These tools often include the capability to develop stored procedures, views (stored queries) and functions for access by scheduled processes and other applications or application modules. Consideration of additional database application licenses should be made for systems that reside on separate hardware.

7.2.2.6 *Maintenance*—The database platform should allow the database administrator to fine-tune the performance and security of the database with functions such as indexing, table space management, and process schedulers.

7.2.2.7 *Personnel*—In situations in which some or all of the laboratory informatics system will be managed and maintained in-house or by parties other than the application vendor, consideration should be given to the availability of technical personnel with skill sets in the technologies utilized by the system.

7.2.2.8 *Backup and Recovery*—The database platform should support industry best practices for backup and recovery in an efficient and expedient manner. This function should

either be included in the database toolkit or supported comprehensively by third-party tools.

7.3 *Laboratory Informatics Application Platform:*

7.3.1 *General Requirements*—Laboratory informatics systems are developed on a wide variety of application platforms, and many standards and programming languages are used which provide adequate features and functions. It is, therefore, important that the vendor provide detailed documentation on the technical capabilities and design of the application architecture. The documentation should allow you to clearly evaluate the flexibility of the application relative to the capabilities needed by your laboratory. An overriding requirement for many organizations is to evaluate the application architecture in the context of its ability to be configured, customized, and integrated with other systems.

7.3.2 *Key Considerations*—When evaluating the application platform, the following capabilities and features should be considered:

7.3.2.1 *Modularity*—The application's functionality at the architecture level should be clearly separated into logical modules with clearly defined standard interfaces between modules. These modules can be defined based upon feature groupings, layering of the application architecture (for example, presentation, business logical, data interfaces) or both. Often this is accomplished through the use of object-oriented design techniques in conjunction with other industry-standard best practice approaches to application design. Design modularity can minimize unexpected consequences of application changes through configuration, customization or integration by isolating the areas of the application affected and facilitating application testing. A modular design also allows the user to deploy additional functionality as the system matures.

7.3.2.2 *Configuration Tools*—The laboratory informatics solution should provide an extensive administrative interface so that end users can configure the application without programming or direct database intervention. These configuration tools should be evaluated for the ability to add, remove, and change design and form elements on the screen to create productive forms and workflows with minimal programming. Additional configuration functionality is often provided through the use of a scripting language to tailor system behavior or build calculations within the application. Ideally, the laboratory informatics solution should allow for customization that incorporates content from external systems such as embedded multimedia (chromatograms, gel plate, short training videos, operating procedures, and so forth).

7.3.2.3 *Laboratory Informatics Solution Software Development Kits (SDK)*—The laboratory informatics solution should provide a programming tool such as a software development kit to address situations where the user requirements cannot be met by the application. The programming tools allow your IS staff to extend the functionality of the application to meet business requirements. The use of industry standard programming tools by laboratory informatics solutions increases the availability of qualified resources to implement and support the system. Caution is recommended when customizing a vendor-supplied laboratory informatics solution to ensure that your system is compatible with future vendor software upgrades. See the section below on customizing laboratory informatics systems.

7.3.2.4 *Laboratory Informatics Application Data Structure*—The laboratory informatics solution and its underlying technology should closely match your organization's laboratory workflow requirements and information structure. The application and database architecture of a system should be assessed on its flexibility to configure, customize and integrate the system to fit the organization's needs.

7.3.2.5 *Performance Design and Data Integrity*—The application architecture should be designed to use the operating system and hardware platform specified as efficiently as possible. This includes evaluation of concurrent usage, peak usage, and the ability for individual end users to multi-task (that is, open multiple screens or application functions in the same user session) without losing work. The use of test automation tools and building a performance-testing model of the system early in the process provides significant benefits and can be used to qualify the final hardware used for deployment. The automation tools can be used to monitor changes in performance, perform regression testing when changes in software are applied, and tune the system as it is developed and even during the operate and maintain phases of the system life cycle.

7.3.2.6 *Personnel*—In situations in which part or all of the system will be managed and maintained in-house or by parties other than the application vendor, consideration should be given to the availability of technical personnel with skill sets in the technologies utilized by the application. Knowledge of supported operating system, programming languages, and design techniques used to customize and integrate with the application are important.

7.3.2.7 *Application Programming Interfaces (API)*—If customization or integration of the system is anticipated, the vendor should be able to provide a well-documented API for interfacing with the application, with a clear model for interfacing with the application's functions at a granular level.

7.3.2.8 *Integration Standards*—The laboratory informatics system should provide a means to integrate and exchange data based on common methods, such as the XML-based SOAP protocol and/or based on the integration methods supported by applications that commonly integrate with the laboratory informatics solution, such as document management systems, manufacturing execution systems and ERP systems.

7.4 *Integration of Laboratory Informatics Solutions:*

7.4.1 *Integration*—The ability of the laboratory informatics product to exchange information with other software systems is an important consideration for most laboratories. In Fig. 2, the categories of systems that are often integrated are illustrated. This may involve either the exchange of data with other applications and/or the exchange of application logic and functionality with other applications. Integration allows for laboratory informatics system to leverage the features of other applications without adding custom features to laboratory informatics system itself. Integrating laboratory informatics

systems may require design changes to the database or application architecture of the laboratory informatics system product. These modifications should, ideally, be minimal if the product is flexible and configurable for integration with other systems.

7.4.2 *Common Laboratory Informatics Integration Activities*—Examples of integrating laboratory informatics solutions with external systems include:

7.4.2.1 Document management systems (standard operating procedures, chain of custody management, reports, and so forth),

7.4.2.2 Training and e-Learning systems,

7.4.2.3 Enterprise Resource Planning systems (ERP),

7.4.2.4 Laboratory equipment inventory and calibration systems,

7.4.2.5 Chemical inventory systems,

7.4.2.6 Manufacturing Execution Systems (MES),

7.4.2.7 Business support systems,

7.4.2.8 Laboratory support systems,

7.4.2.9 Web portals,

7.4.2.10 Data warehouses, and

7.4.2.11 Field data capture systems.

7.4.3 *Business Considerations for Integrating Laboratory Informatics Systems with Other Applications*—One of the most critical evaluation criteria in the selection and implementation of any system is the organization's need for the customization and integration of the laboratory informatics system and the capabilities of the candidate system to perform these functions flexibly. Integrating the laboratory informatics system with other systems can profoundly impact product selection, implementation, ongoing management, and total cost of ownership of the system investment. Additional information on integration options is given below in 7.9. The decision to customize the laboratory informatics solution for a particular business purpose or integrate the application with another information system shall follow a formal process that forms a part of the system life cycle. For a more detailed explanation of the business and management considerations of system integration, see Section 8.

7.5 *Enterprise Computing Architecture*—Fig. 2 provides a conceptual model of related laboratory informatics solutions. Fig. 7 illustrates an example of an integrated enterprise computing architecture that spans from enterprise systems down to the bench level laboratory analytical systems (instruments). Other architectures are also used such as configuring a LIMS, SDMS, LES or ELN to serve as the Enterprise Integration Platform without the extra service layer depicted in Fig. 7. A CDS, on the other hand, as well as other instrument control and data analysis software could form an additional layer between LIMS/SDMS/LES/ELN and the actual instruments.

7.5.1 *Multi-Site Deployments (Globalization or Corporate Multi Site Deployment)*—Globalization is the process and environment by which companies conduct business (internal activities and commerce with others) in many countries across

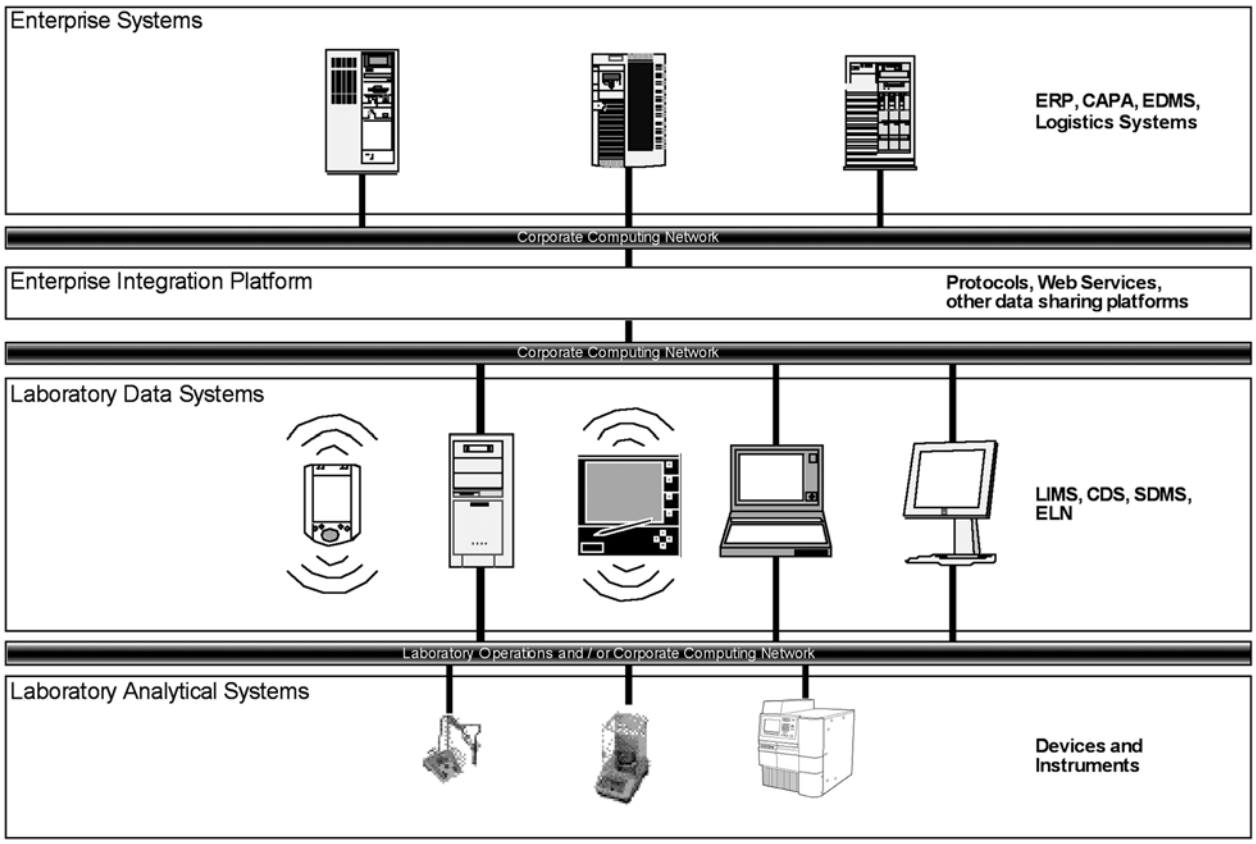


FIG. 7 Conceptual Laboratory Informatics and Corporate Computing Architecture

the globe. The advent of advanced communications technology such as the internet and the rapid expansion of trade (among other factors) have greatly distributed scientific activities in general and laboratory environments in particular across the world. In Table 1, the benefits and challenges of different deployment strategies to be considered during multi-site laboratory informatics solution implementations are described.

7.5.2 *Content Localization*—Content localization provides a user interface that reflects the specific geographic needs of each user and generally involves three elements (language, character sets, and time zones), with each value usually set in the user's application profile or in the local installation.

7.5.2.1 Language localization is a translation of the language in the user interface for the local user. It is generally a configurable item in global deployments, usually driven by database language content, configuration files, and/or an XML-based user interface framework.

7.5.2.2 Character sets refer to the set of characters employed to express the selected language in the user interface. The choice of character sets is particularly important when considering user interface customizations. Unicode character sets are often used to address specifically local language issues without impact to the rendering of the user interface.

7.5.2.3 Time zone refers to the specific local time zone used by the system for time stamps and audit trail purposes. It is especially important to be mindful of time zone configurability in a system when storing, comparing, or aggregating data across multiple time zones, such that the audit trail can be preserved. Expressing the time as an offset of Coordinated Universal Time (UTC) for each time zone unifies this information (for example, U.S. Eastern Standard Time is UTC–5 h) is commonly used within laboratory informatics implementations.

7.5.3 *Regulatory and Functional Issues*—Globalization issues include specific functional needs across regulatory jurisdictions and other functional issues derived from the local laboratory environment. These issues can either be handled through configuration (for example, FDA 21 CFR Part 11 support) or customization. It is important in these scenarios that customizations are performed with upgrade path, support, and impact to users in other locations in mind.

TABLE 1 Multi-Site Laboratory Informatics Solution Deployment Strategies

Description	Benefits	Challenges
Central deployments house the entire laboratory informatics solution in one or more data centers with all application functions centrally managed. User interface is delivered via a web browser or thin client terminal (including remote desktop).	Consolidates support resources. Changes to the system are available to users in all locations quickly. Minimum local IT support required. Deployment to new locations can be quicker and easier than with distributed systems. Data are centralized, making it easier to gather and analyze business intelligence across organization. Regulatory and management standards can be easier to harmonize and enforce across sites.	Application architecture is critical to the flexibility of laboratory informatics solution for local laboratory needs. System shall be highly configurable to smoothly handle local language and regulatory issues. Customized features shall be analyzed to insure that the entire user community benefits (and is not otherwise harmed) by the changes. Infrastructure shall be carefully planned for network availability and redundancy.
Regional deployments combine the economies of scale of the central model with the flexibility of the distributed model. Clusters of laboratory informatics solution users are defined with common geographic, regulatory or usage communities so that laboratory informatics solution implementations can be centralized into a few installations while still meeting the core application needs of each group.	Delivers a happy medium between cost savings from economies of scale and delivering the right return on investment to meet user needs. Local IT support is still minimized, since this method generally uses a "thin client" approach. Deployment to new locations is still relatively quick and easy compared to a fully distributed model. Changes and upgrades can be delivered quickly while maintaining flexibility. Data are still more easily aggregated across common business needs. Regulatory and management standards can be easier to harmonize and enforce across sites.	User clusters shall be defined carefully, or the result is simply a higher-cost centralized model. User requirements shall be clearly aligned across language, regulatory and functional needs so that the system can be properly configured. Customizations and upgrades shall be carefully synchronized, both among the region's users and across the organization. Careful infrastructure planning shall be done to make sure system availability is not affected by regional events.
Distributed deployments consist of either stand-alone fat client desktop applications, or a client-server model, with a server installation at each location. Distributed models are generally not used when globalization is a significant issue.	Content localization is out-of-the-box, since there is an installation for each location which is configured for local needs. Configuration and customization can be performed largely without regard to needs beyond the local deployment. Ideal where each location's needs are clearly separate from one another and/or functional differences by location are clearly delineated. Network availability is generally confined to more manageable local network (LAN) issues versus more complex wide area network issues.	Deployment, maintenance, upgrades, infrastructure and support can be very costly since each specific installation shall have these resources available. Determining a global strategic direction for aligning laboratory informatics solution with the organization is difficult, due to a high degree of local variance. Lack of standardization. Common regulatory and management standards are difficult to automate across the organization, and benefits from one deployment are difficult to translate to another location. Data aggregation to analyze and report on global operations is nearly impossible with highly distributed data sources. Disaster recovery plans are difficult and/or costly to implement since each plan and implementation will vary by location.

7.5.4 *User Security*—User security varies greatly by technical implementation across laboratory informatics systems, but in general, systems should be evaluated according to the following basic user security issues: *(1)* Does the security framework provided by the system provide audit trail and permission control in a comprehensive manner as compared to the needs of the organization? *(2)* Is the security framework flexible and granular enough to allow control of security at a functional or task level? *(3)* Can the security framework be conveniently administered, with a single security framework for all modules of the system, and can it be integrated with other enterprise frameworks? Laboratory informatics system security frameworks generally support the following capabilities at the user, group, and enterprise level:

7.5.4.1 *User Security:*

(1) Audit Trail—The system should minimally be able to provide a user id and timestamp on all data activities a user performs (insert, update, and delete) and allow that data to be accessible for audit trail reporting.

(2) Single Sign-on—Most systems have a unified authentication scheme whereby a user can log in once and access all of the functions for which he/she has permission without requiring an additional log in.

(3) Session Timeout—The authentication scheme should also allow a configurable setting for requiring the user to enter user name and password again when the user has been idle on the system for more than a configured period of time (this is sometimes managed outside of application by the enterprise network settings).

(4) Password Policy—The system should meet your company standards for requirements on password renewal, password combinations (that is, minimum character lengths and combinations of characters and numbers), and encryption strength of database password storage.

(5) Regulatory Compliance and Electronic Signatures—The system should comply with applicable regulatory standards and company standards where electronic signatures or user acknowledgement of electronic records or both are used.

7.5.4.2 *Group Security:*

(1) User Assignment—The system should support the ability to assign individual users to system groups or roles.

(2) Query Assignment—The system may optionally allow assignment of users in batch by querying other user information, such as department.

(3) Functional Assignment—The system should allow for the assignment of permissions to groups for specific operations in the laboratory informatics system, such that a single group can have a standard set of permissions for a configurable set of granular activities (for example, performing specific data entry tasks, running specific reports or categories of reports, and so forth).

(4) Audit Trail—The system should provide an audit trail (user id, timestamp, and reason) of all changes to group membership or group permissions.

7.5.4.3 *Enterprise Security:*

(1) Enterprise Directory or Network Security—A laboratory informatics system may optionally integrate with an organization's enterprise security directory (for example, LDAP, active directory, windows domain, and so forth). This feature provides the benefit of a single set of credentials for multiple applications, seamless integration for laboratory informatics system into corporate security policies, and more convenient and robust security administration of users (for example, removing a user in the directory removes the user's access to all applications, rather than requiring the user to be removed from user databases in each application).

(2) Integration with Physical Security Systems and Public Key Infrastructures—A system's security framework may also optionally integrate with an organization's physical security systems, such as security badges or biometric devices. These security systems supplement user identification/password credentials with encrypted certificates, smart card systems, and so forth. These features provide an additional validation and audit trail for authenticating users, and (with the appropriate device integrated with system access) may provide the additional convenience of passive authentication to the laboratory informatics system rather than manually typing in a user id and password.

7.5.5 *Infrastructure*—The network and hardware infrastructure required by a laboratory informatics system varies widely by the particular software and feature package chosen, but it is especially important to understand what network and equipment resources will be needed depending upon your chosen deployment method (central, regional, distributed). In Table 2, a summary of the common infrastructure requirements and choices based on deployment strategy is listed.

7.6 *Exchange of Data between Laboratory Informatics Systems and Enterprise Resource Planning (ERP Systems)*—Interfacing laboratory informatics systems and ERP to enable an integrated quality management function as detailed in the chart below is a common requirement in a quality control laboratory environment where both systems are deployed. The inspection requirements arise from the passage of materials along the supply chain managed by the ERP logistics modules. Data sharing between systems can facilitate a more rapid and efficient quality control/production process through the life cycle of each production batch (Fig. 8).

7.6.1 *Integration Points between Laboratory Informatics Systems and ERP*—In Fig. 9, the basic integration points between laboratory informatics systems and ERP systems are outlined.

7.6.2 *Integration Options*—Approaches to facilitate laboratory informatics systems integration with other systems range from the creation of customized interfaces to vendor provided configurable solutions. An array of technologies and techniques exist to help facilitate integration. System vendors may provide specific certified interfaces for ERP integration, which removes much of the burden of custom development and costly maintenance from the implementer. The ISA 95 Enterprise/Control System Integration standards[12] are also highly relevant and widely supported by many ERP and MES vendors. The standards describe integration between the business logistic management layer, which includes ERP systems, and the

[12] Available from International Society of Automation (ISA), 67 Alexander Drive, Research Triangle Park, NC 27709, http://www.isa.org

TABLE 2 Infrastructure Requirements by Deployment Strategy

	Central	Regional	Distributed
Network Configuration	Wide-area network or virtual private network	Wide-area network or virtual private network	Local-area network
Security Infrastructure	Enterprise directory or internal laboratory informatics solution database	Enterprise directory or internal laboratory informatics solution database	Internal laboratory informatics solution database or local domain
Backups and Redundancy	Daily or continuous incremental data backups automatically to offsite location. Redundant data centers. Redundant network access points.	Daily or continuous incremental data backups automatically to offsite location. Redundant data centers, or shared failover between regional centers. Redundant network access points.	Daily backups with manual transport to offsite storage. Usually no data center or network redundancy.
Hardware Configuration	Mainframe or multiple-CPU servers with fully redundant components (server, motherboard, memory, disk, power supply, and so forth). Thin client configuration (terminal, remote desktop, web browser).	Multiple-CPU servers with fully redundant components (server, motherboard, memory, disk, power supply, and so forth). Multi-tier (desktop application with database and application server on back-end) or thin client configuration (terminal, remote desktop, web browser).	Departmental server with minimal redundancy or no server (for deployments with a low number of clients). Client-server (desktop application with database and application server on back-end) or standalone desktop configuration with local data store.

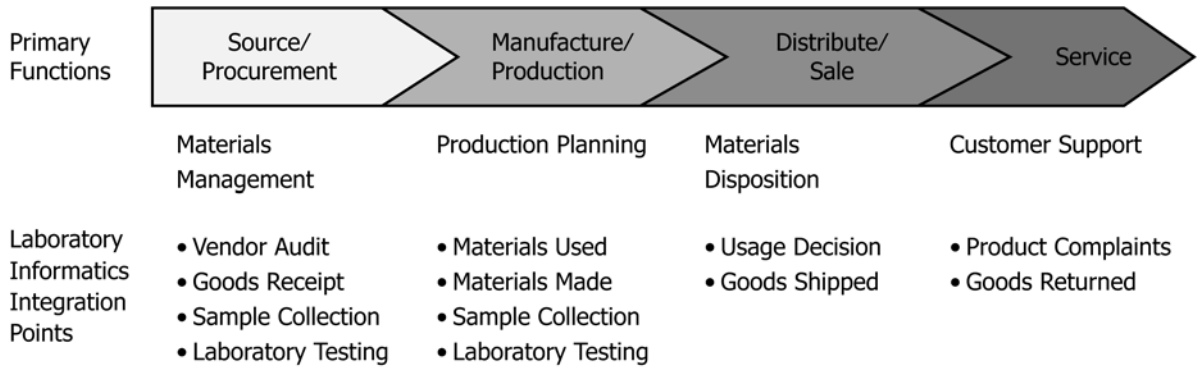


FIG. 8 Laboratory Informatics Solution—ERP Integration Points

manufacturing operations management layer, which includes MES and laboratory informatics systems (Fig. 10). The World Batch Forum has developed XML schemas that map to the ANSI/ISA-95 models. These define how to represent the ISA-95 information in XML, known as Business to Manufacturing Markup Language or B2MML V2.0.

7.7 *Instrument Integration:*

7.7.1 Integration of laboratory informatics systems with instruments requires interfacing two moderately complex or highly complex systems. Interfaces between the laboratory informatics system and laboratory instruments [such as balances, pH meters, spectrophotometers, chromatography data systems (CDS)] typically involve interfacing the system directly to the instrument or to another data system controlling the instrument hardware such as CDS. The CDS is typically addressed as a specific category because of its inherent complexity. Instrument integration with the laboratory informatics system can be a key factor in delivering effective cost benefits for the implementation.

7.7.2 Because of the inherent complexity of managing instrument sample test sequences (in some cases, an auto sampler) in both the laboratory informatics system and the laboratory instrument data system, it is highly desirable that the laboratory informatics system down load a test sequence to the laboratory instrument data systems via an interface to assure accurate exchange of information.

7.7.3 The laboratory instrument data system performs the measurement and transfers back to the laboratory informatics system the results for further processing. The laboratory instrument test result (determination, measurement) is transferred via the laboratory informatics system-instrument interface. Alternatively, the laboratory instrument data system may pull from the pertinent sample identifiers, perform the necessary measurements, and then push back the results to the laboratory informatics system.

7.7.4 In many cases, it is highly desirable that the result transfer from the data system to the laboratory informatics system be done in real time such that further result processing (cross-technique calculations, approvals, reporting, and so forth) be done as soon as the measurements have been performed.

7.7.5 Choosing which system will perform automated calculations should be guided by the functionality each system (laboratory informatics system versus laboratory instrument

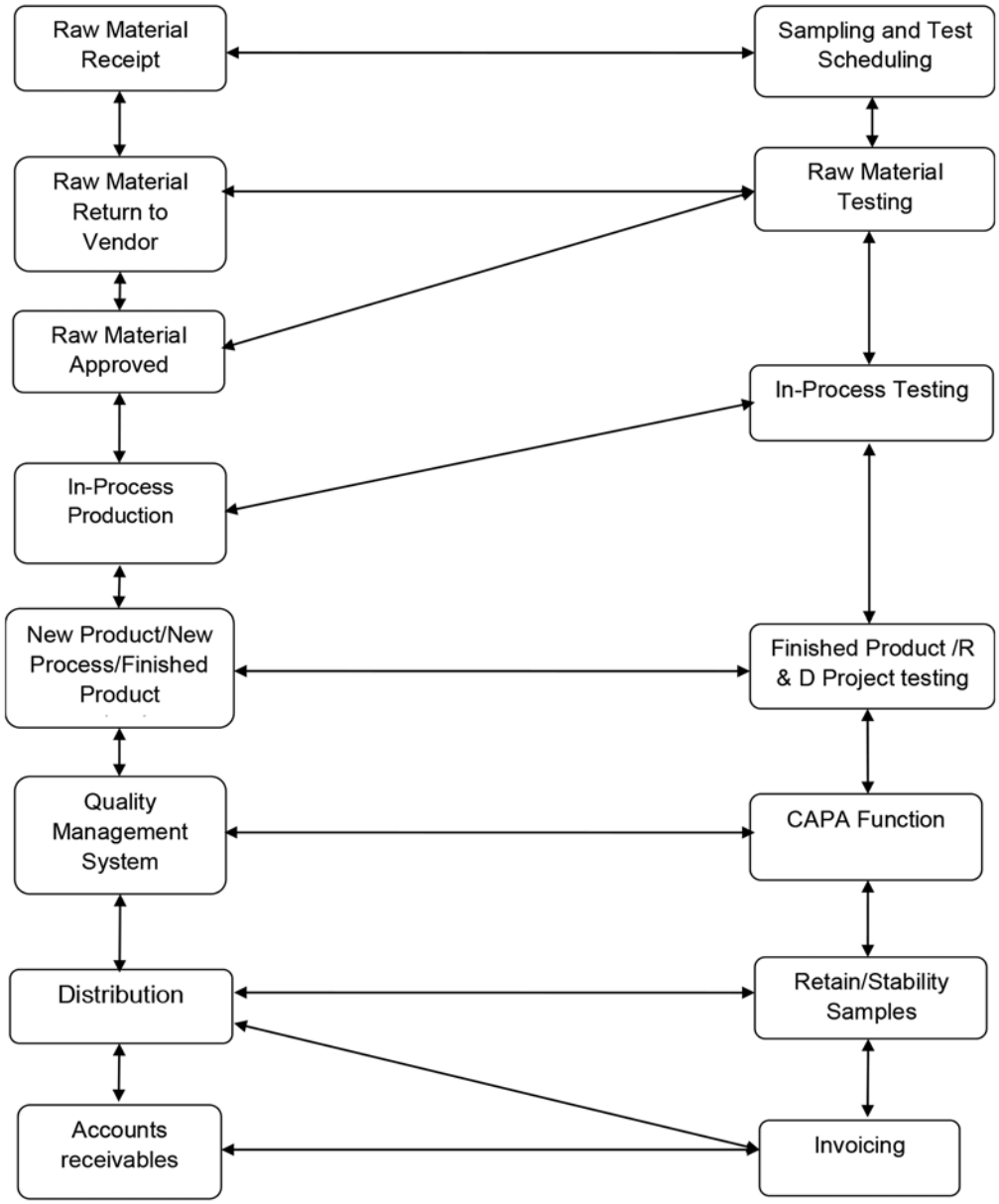


FIG. 9 Possible Points of Data Exchange between ERP and Laboratory Informatics Solution

data system) provides. For example, the CDS typically includes calculations for system suitability, peak integration, and calibration curves while a LIMS performs cross-technique calculations, correcting for moisture and other factors, and results trending across multiple techniques and time. Typical approaches for LIMS-CDS calculations include the use of ratios where the CDS reports a sample response over a standard response and the LIMS is used to calculate the final result and compare it to specifications and further reporting.

7.7.6 The interface between the laboratory informatics system and the instrument ideally should not require the creation of an intermediate file as files represent security risks or an increase to overall system complexity to mitigate this risk. The XML data standard represents the industry standard as the information format to exchange structured data between two systems. Furthermore, XML can be permanently stored as files or temporary exchanged as a stream between two cooperating applications. Because of its broad acceptance, XML format is recommended as the base format for interface to instruments. Industry standard tools (such as XSL) can be used to transform the data representation from one vendor to another, again increasing the value of an XML-based interface.

7.8 *Industry Data Exchange Technology:*

7.8.1 In this age of increased electronic communication, it is common for data users to request and report laboratory data in a standardized electronic format also known as an electronic data deliverable (EDD). There are many types of EDD formats

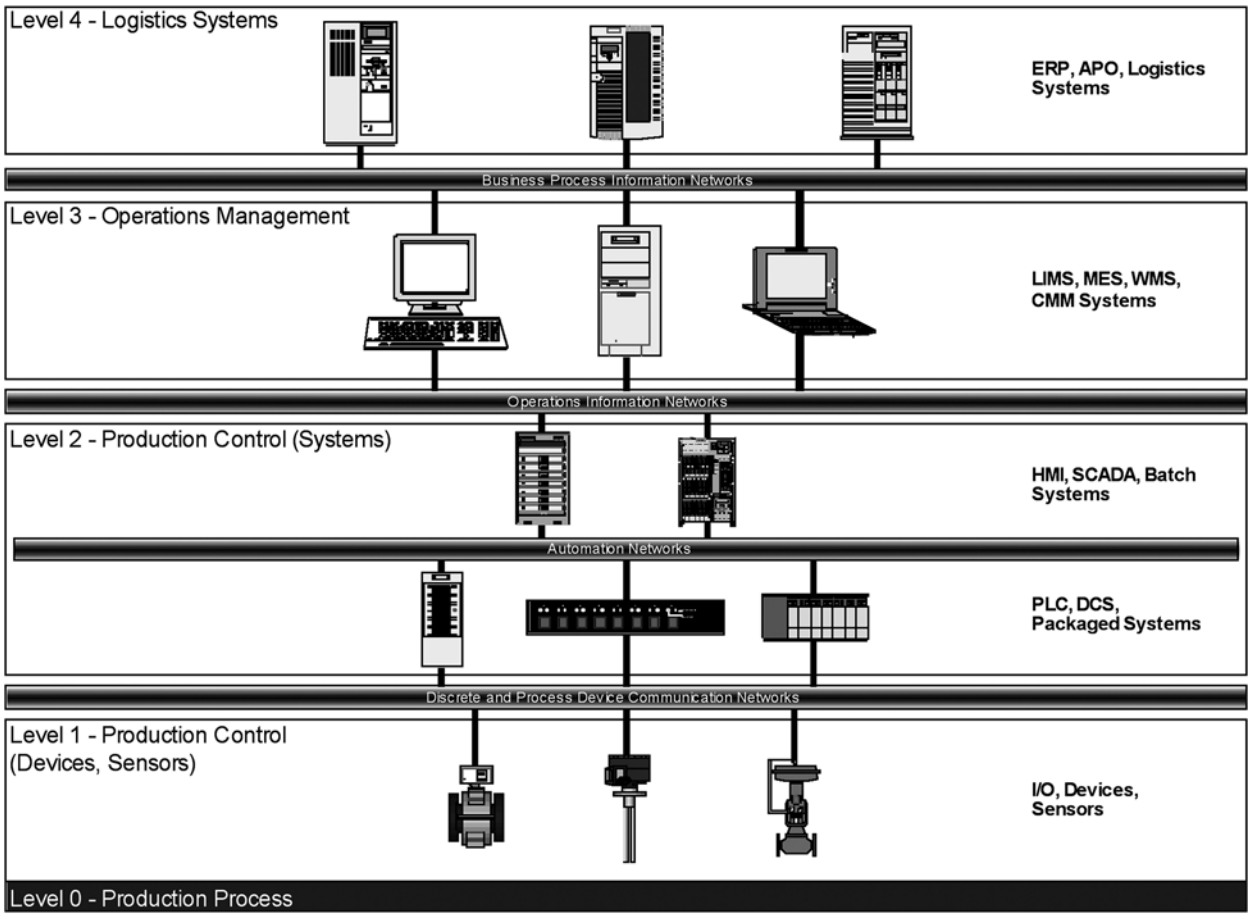


FIG. 10 ISA-95 Conceptual Information Technology Topology

and potentially multiple versions within a format. Using EDDs saves time by sending data directly from a laboratory informatics system such as LIMS, minimizing and possibly eliminating manual data entry through automation, reducing transcription errors, allowing data delivery in a secure manner, and decreasing the need to harmonize and cleanse data. Electronic Laboratory Reporting (ELR) is an example of a national effort to share clinical laboratory health data with public health agencies and has been a driving force for data standardization along with reporting clinical and environmental data for national emergency response activities and regulatory compliance across many state and federal agencies.

7.8.2 Both public and private laboratories together can be viewed as nodes to a large network of laboratories that share data and can work interoperably to integrate their collective data into a single data feed. This data originates at a laboratory informatics system. The ability to integrate this data is complicated by the many variations in laboratory informatics systems and the many different functional requirements and "standards" utilized by recipient agencies and clients. As the client/agency needs differ both in content and in formatting of the data message the laboratory results communicated from their laboratory informatics system shall reflect different program needs, vocabulary, data elements, message structure, and secure transport.

7.8.3 Utilization of standards for laboratory informatics implementations is an effective way to reduce implementation costs, improve networking capability of both public and private laboratories, and achieve efficiency of laboratory informatics interoperability. Laboratory informatics solutions shall take into account the many system architecture options that a laboratory may use to submit electronic data on reportable laboratory results to clients/agencies as required by state or local laws and practice.

7.8.4 In cases in which data is exchanged between a large diverse set of public and private laboratories where patient information or other metadata and demographic data is also exchanged, the data standards for message and content structure such as Health Level 7 (HL7)[13] have been developed. Data content standards such as Systematized Nomenclature of

Medicine-Clinical Terms (SNOMED-CT)[14] and Logical Observation Identifiers Names and Codes (LOINC)[15] provide consistent ways to store, retrieve, and aggregate clinical data across specialties and sites of care.

7.8.5 Electronic Laboratory Reporting (ELR)[16] is the electronic transmission from laboratories to public health of laboratory reports which identify reportable conditions. ELR has many benefits, including improved timeliness, reduction of manual data entry errors, and reports that are more complete. Electronic laboratory reporting has been promoted as a public health priority for the past several years and its inclusion as a meaningful use objective for public health serves as a catalyst to accelerate its adoption. The Centers for Medicare & Medicaid Services (CMS) have launched the "Medicare and Medicaid Programs: Electronic Health Records Incentive Program" to provide incentive payments to Eligible Professionals (EPs), Eligible Hospitals (EHs) and Critical Access Hospitals (CAHs) participating in the Medicare and Medicaid programs, that adopt and successfully demonstrate meaningful use of certified Electronic Health Records (EHR) technology. The Stage 1, meaningful use objective and measure for reportable laboratory results are:

7.8.5.1 *Objective*—Capability to submit electronic data on reportable (as required by state or local law) laboratory results to Public Hospitals (PH) agencies and actual submission in accordance with applicable law and practice.

7.8.5.2 *Measure*—Performed at least one test of EHR's technology's capacity to provide results electronic submission of reportable laboratory results to public health agencies and follow–up submission if the test is successful.

7.8.6 While the reportable laboratory results meaningful use objective promotes adoption by hospitals and laboratories, it does not address state challenges in receiving the data nor does it provide vendors and laboratories practical implementation guidelines for providing electronic laboratory reports to public health.

7.9 *Enterprise Application Integration and Middleware*—Organizations with a defined enterprise application integration strategy, or a standard enterprise middleware platform should evaluate the laboratory informatics system for its ability to integrate easily with the middleware's supported standards. Integration with a central middleware platform can substantially reduce integration costs and complexity. A single integration implementation of the system to the middleware platform can then potentially support information exchange with multiple enterprise applications connected to the same middleware hub.

7.9.1 The middleware platform can consist of standards-based integration broker software. An integration broker, built primarily on messaging middleware, provides an end-to-end integration platform to handle components of data exchange between laboratories and data consumers. Vocabulary, messaging, and transport are automated across the extended enterprise, which includes the data exchange partners. It provides wide-ranging, prebuilt application adapters, and bidirectional connectivity to multiple applications, including packaged and mainframe applications. In this configuration, the integration broker component of the system filters and maps the data, converting local codes to standard codes, and generates valid message structure and content before securely transmitting it using the agreed-to transport mechanism. The message broker/integration engine can be a separate standalone capability or integrated with the laboratory informatics solution. See the Bibliography for clinical and health data standards for more information on networks which are used to exchange different types of information including public health, food alerts, drug safety and environmental data at a national level.

7.10 *Digital Content*—A wide array of digital media (images, site and corporate SOPs, reports from miscellaneous instruments, user training records, supplier reports, and so forth) are stored in a secure way in the laboratory. Storage and management of these supporting documents and electronic records are typically in external SDMS or data archive systems with links to the laboratory informatics system. Access to these digital content sources can be accomplished through a wide range of technical solutions (enterprise data share, content management system, and so forth). Access to this data storage from the laboratory informatics system is highly desirable, especially if integrated into the system workflow through configuration.

7.11 *Electronic Laboratory Notebook (ELN) Integration*—The integration of two laboratory informatics solutions such as an ELN with a LIMS can take many forms dependent on the business functions performed by each system. Electronic laboratory notebook functions vary widely but are generally in two categories, specific ELNs and cross-disciplinary ELNs. Specific ELNs contain features designed to work with specific applications, scientific instrumentation or data types. Specific ELNs can be closely integrated with a LIMS to pass information from LIMS to the ELN and from the ELN to LIMS. Cross-disciplinary ELNs or generic ELNs are designed to support access to all data and information that needs to be recorded in a laboratory notebook and are typically integrated with a LIMS as a pointer or reference within the LIMS. Specific LIMS implementations can vary between a full implementation that covers the laboratory bench and instrument integration up to final results and material (lot) disposition (with LIMS performing the function of an ELN) to more limited implementations where the LIMS manages the final result but does not fully cover the laboratory bench or instrument integration functions and the ELN manages information on the laboratory bench and integration with instruments and passes this information to LIMS. ELN Integration is not limited to LIMS. Integration with an SDMS or other laboratory informatics solutions is commonly done as well.

[14] Available from International Health Terminology Standards Development Organisation (IHTSDO), Gammeltorv 4, 1., 1457 Copenhagen K, Denmark, http://www.ihtsdo.org

[15] Registered trademark of and available from The Regenstrief Institute, Inc, 410 West 10th Street, Suite 2000, Indianapolis, IN 46202-3012, http://loinc.org

[16] Electronic Laboratory Reporting relevant to July 28, 2010, Center for Medicare and Medicaid Services "meaningful use" regulations that address automated electronic laboratory reporting to public health. Data is transmitted using Health Level 7 messaging via secure transport such as PHIN-MS or NHEN Direct. Additional information available from Centers for Disease Control and Prevention (CDC), 1600 Clifton Rd. Atlanta, GA 30333, http://www.cdc.gov/ehrmeaningfuluse/elr.html.

7.12 *Reporting and Business Intelligence*—Many laboratory informatics solutions include the ability to generate simple reports. Integration with other report generation applications can provide additional features such as quality control charts, data mining, business performance management, and other statistical analysis. This may also include configuration of data exports or database views to external reporting systems or data warehouses/marts, or integration to information dashboards and portals.

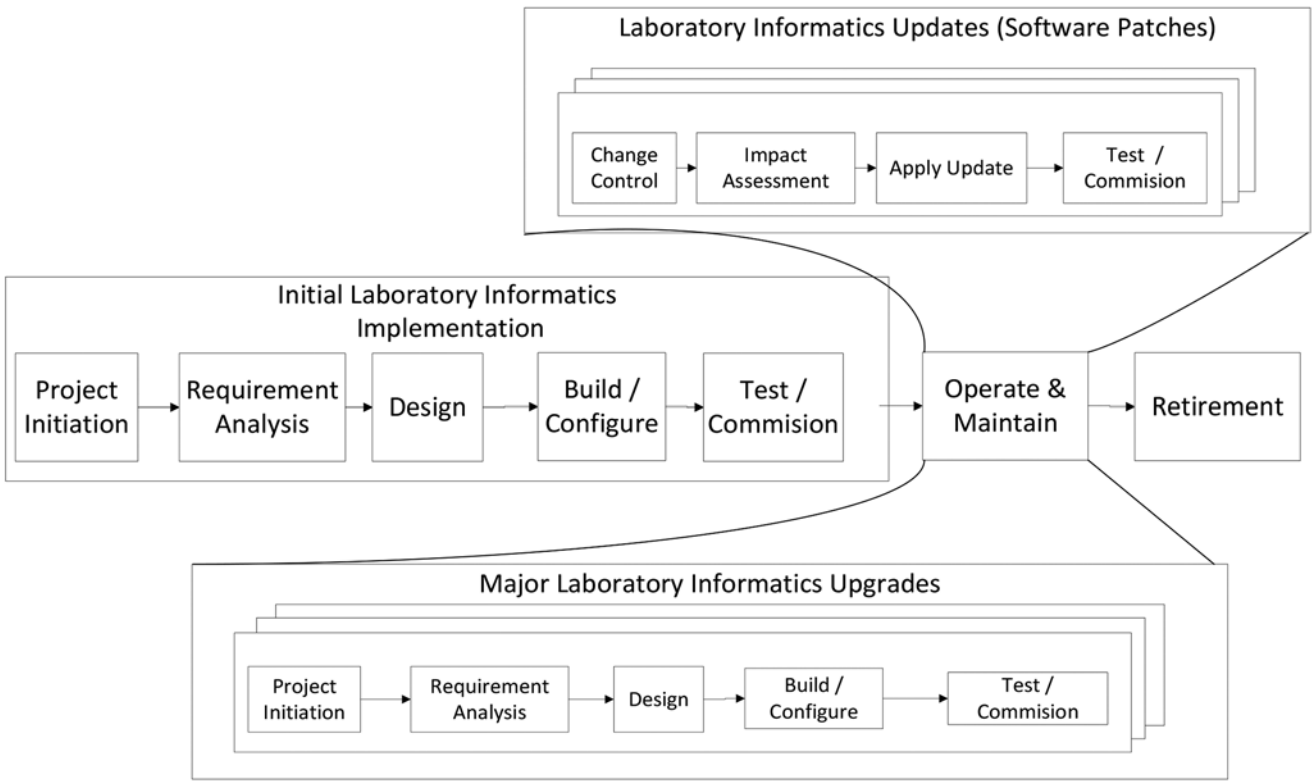
7.13 Laboratory informatics solutions can be deployed on a computing infrastructure installed and supported entirely by a company's internal resources. Alternatively, companies can chose to use computing services purchased from external suppliers and delivered over the public Internet or a private network. There are many types of public cloud computing services available including:

7.13.1 Infrastructure as a service (IaaS),
7.13.2 Platform as a service (PaaS),
7.13.3 Software as a service (SaaS),
7.13.4 Storage as a service (STaaS),
7.13.5 Security as a service (SECaaS),
7.13.6 Data as a service (DaaS),
7.13.7 Test environment as a service (TEaaS),
7.13.8 Desktop as a service (DaaS), and
7.13.9 API as a service (APIaaS).

7.14 The benefits of using a cloud laboratory informatics service include lower start-up costs with on-going expenses rather than upfront capital purchases, flexibility in the number of licenses deployed, and guaranteed service levels for the application. Some of the negatives of a cloud-based laboratory informatics service are more complicated compliance issues, requirements to follow the service provider with upgrades (for example, web browser versions, desktop applications, operating systems, database environments), user and data security considerations, more difficult to integrate with other systems, and potentially higher costs of ownership over the system lifetime.

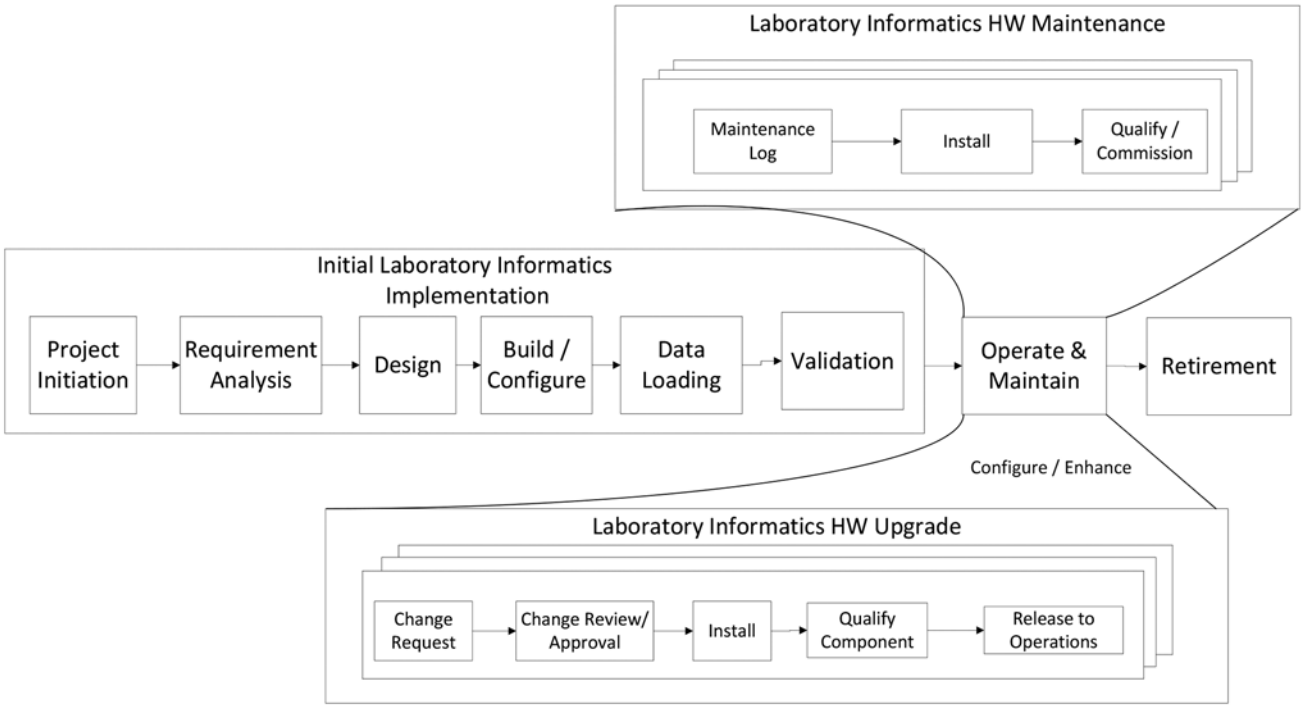
8. Laboratory Informatics System Life Cycle

8.1 *Introduction*—The system life cycle refers to the activities that are taken to acquire, implement, operate, and eventually retire a laboratory informatics system. A typical laboratory informatics system life cycle is illustrated in Fig. 11 (overall system life cycle) and Fig. 12 (typical hardware life cycle). The system lifecycle starts with the implementation. This may be the introduction of an informatics system to replace manual procedures in the laboratory or the replacement of an obsolete legacy system. The project length will be driven by a number of factors. The degree of configuration or customization or both that is necessary to meet organizational requirements and the resources available to the project—both internal and external—are examples of factors that will impact the project timeline. Based on these factors, a laboratory informatics project may take from several months to well over a year to complete. The implementation lifecycle phase is followed by an operational phase, when the system is used to manage data



A typical laboratory informatics system life cycle. While many of these activities shall occur simultaneously, the system life cycle may be better visualized by organizing the activities into sequential phases for the purpose of facilitating planning and providing checkpoints for managing the project.

FIG. 11 Laboratory Informatics System Life Cycle



In addition to software updates (Fig. 11), hardware upgrades shall be properly accounted for and managed during the operational and maintenance phase of the life cycle.

FIG. 12 Laboratory Informatics System Life Cycle—Hardware

and workflow. The system will evolve during the operation and maintenance phase. Support resources will maintain and add enhancements through the use of configuration and customization tools. The supplier will provide updates and upgrades as improvements are made to the product. Hardware and software infrastructure may be updated. The operation and maintenance phase length is highly dependent upon a number of factors and typically lasts years, concluding when the system is retired. Retirement will occur when the system or underlying infrastructure becomes obsolete, or when business requirements dictate a new direction for the system.

8.1.1 *Laboratory Informatics Life Cycle Phases—Overview:*

8.1.1.1 Project initiation is the first phase in the initial laboratory informatics system implementation and also for major system upgrades that occur during the operation and maintenance phase. During this phase, the project or upgrade is conceived and the business case is developed including a preliminary estimate of costs and benefits. The initial scope and boundaries of the project are determined as part of project initiation. The Functional Requirements Checklist in Appendix X1 provides a useful tool for identifying functions having significant benefit, prioritizing them, and bounding the scope to those functions that will insure a manageable project and justify the effort. At the completion of this step it is prudent to review costs and benefits with management to verify that the project is viable in the context of business issues such as cash flow, resource allocation, and priorities before investing significant effort in requirements analysis and vendor selection.

8.1.1.2 Requirements analysis is the phase for determining what functions and features are required and determining how the laboratory informatics system will support the laboratory work flow. Requirements analysis occurs during the initial implementation and also for major system upgrades. Requirements provide the basis for the laboratory informatics system selection. A laboratory informatics product is typically selected during the requirements analysis phase during the initial implementation. It is critical in this phase to verify that the required functionality is either available in a usable form in vendor offerings or to include customization in the project scope. For commercial-off-the-shelf (COTS) systems, this is often best accomplished by targeted configuration and demonstration of the actual workflow from beginning to end with a critical eye to exceptions and unusual cases that are inherent in any laboratory operation. For larger projects it may be justified to include a vendor audit, visit a customer site, and/or conduct a pilot project before committing to a substantial investment.

8.1.1.3 Design is the phase in which system functional requirements are translated into detailed logical and physical design specifications. Design occurs during initial implementation and during major upgrades. For COTS systems, this phase consists of specifying how the laboratory informatics product features will be used and configured to meet the requirements.

8.1.1.4 Build/configure is the construction phase of the laboratory informatics system. Activities include development, customization, configuration, and developmental testing of the solution being implemented. Build/configure activities occur during both initial implementation and during major upgrades. Methods such as iterative prototyping cycles of design and build/configure help insure a successful implementation with minimal rework.

8.1.1.5 Testing and commission is the phase during which the solution is put into operation. Activities include validation testing, data loading, final acceptance and deployment. Reference GAMP 5 for detailed guidance on validating the informatics solution in regulated environments.

8.1.1.6 Operation and maintenance is the phase in which the system is used to support the laboratory operations in production. Maintenance and support is performed on the laboratory informatics solution to keep it aligned with changing business and technology requirements. The implemented solution evolves through updates and upgrades. Updates usually involve small changes to address software bugs with the system. These updates can be applied to the system after their impact is analyzed. Upgrades are provided when the vendor makes improvements in their product. Implementing an upgrade typically involves applying new functionality in the laboratory, or is required to operate under changing IT infrastructure. Applying upgrades can be a major project and follows a process similar to the initial implementation activities.

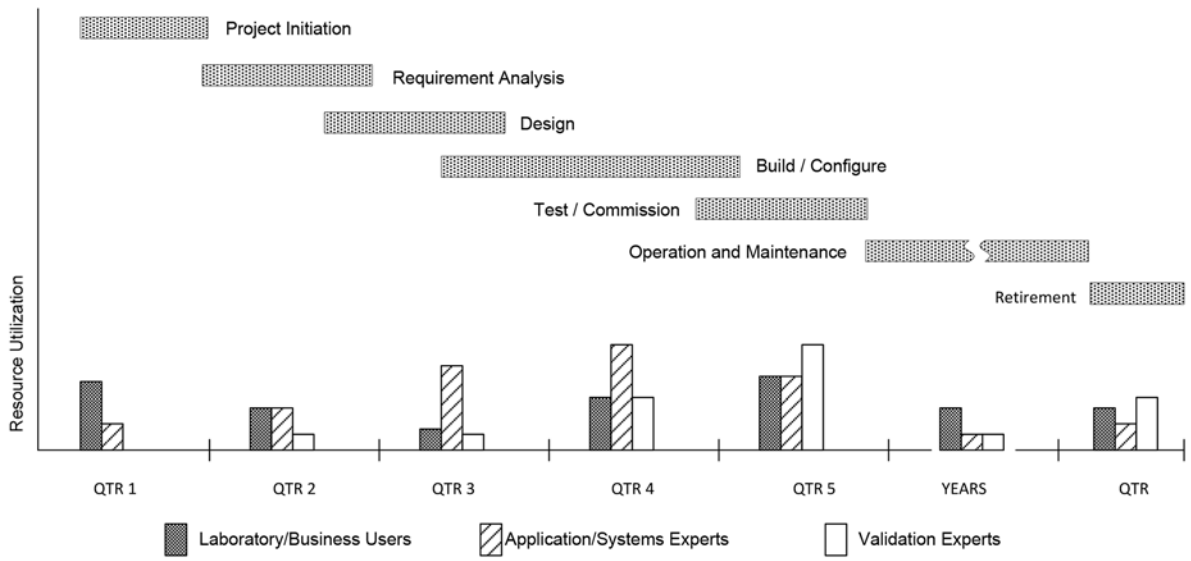
8.1.1.7 Retirement is the final phase in the system life cycle. Usually driven by technology obsolescence, retirement involves planning for the next generation solution, including providing access to relevant historical laboratory data.

8.1.2 *Laboratory Informatics Life Cycle Implementation Project Flow*—The flow for a typical implementation and system life cycle is illustrated in Fig. 13.

8.1.2.1 The time frames depicted in Fig. 13 are illustrative only, and vary widely depending upon how closely the base functionality of the laboratory informatics solution matches the user requirements, the requirements for customization and the different types of activities carried out in the laboratory. The implementation could provide complete functionality to support the operation or the scope of the initial project reduced to the most beneficial functions if resources are limited, with provisions for subsequent expansion of use by configuration and customization. When the project team establishes the level of customization and configuration the team needs to take into consideration: *(1)* resource availability; *(2)* time remaining to the laboratory informatics solution go-live date; *(3)* scope of the project; and *(4)* project budget constraints. These constraints will help guide the teams' efforts towards a successful implementation that provides the maximum benefits within the business constraints. The degree of effort, cost, and time necessary to successfully complete validation of the laboratory informatics solution will be driven by a number of factors, such as the complexity of the solution being implemented, the complexity of the business processes, and the validation methodology used by the organization. Validation typically includes risk assessment, installation qualification of the system, operational qualification of the system, performance qualification of the system, verification of calculations, and user acceptance testing to verify work flow and user requirements.

8.1.2.2 Note that while the phases occur sequentially, design could start before completion of requirements and build/configure could start before completion of design. This would occur particularly with a prototyping implementation in which feedback from user review is used to adjust the design. Build/configure is normally the longest and most difficult phase during initial implementation and also during major upgrades. The operate/maintain phase is the longest phase in the life cycle and should last as long the laboratory informatics solution supports the business needs, and may include upgrade activities to the solutions software, hardware, database, and operating systems. More comprehensive descriptions of the activities in each of the system lifecycle phases are provided in 8.2.

8.1.2.3 Laboratory users are heavily involved in the business planning that occurs during project initiation and requirements analysis. They have less involvement during the design



An illustration of relative resource utilization during various phases of the informatics system life cycle. Three types of resources are illustrated including laboratory or business users, application/systems experts or developers, and validation experts. The expert, developer, and validation roles may be fulfilled by external consultants if internal resources are not available.

FIG. 13 Laboratory Informatics System Life Cycle—Resources and Timeline

phase but get re-engaged during build/configure and are normally heavily involved in the test/commission phase. Laboratory/business users provide administration and support and participate in updates and upgrades during the operate-and-maintain phase. Project management should recognize that laboratory users will need to be freed from their day-to-day activities to participate successfully within the project.

8.1.2.4 Support from laboratory informatics solution experts is useful during project initiation and also during requirements analysis when they contribute an understanding of the solution's functionality and what is reasonable and feasible. These experts do the bulk of work during the design and build/configure phases. They also provide support for the test/commission phase and during the initial operation phase.

8.1.2.5 In regulated environments, validation experts get involved during the requirements and design phase to begin validation planning. They write test scripts during the build/configure phase. Their heaviest involvement occurs during the test/commission phase when they facilitate execution of system validation.

8.1.3 *Factors Affecting Laboratory Informatics Projects*—As with any complex project, laboratory informatics projects shall be planned, managed, and delivered within the constraints of scope, time, and cost. Additional constraints include resources, risk, and quality.[17] Changing scope or resources in an informatics project, for example, will likely affect projected implementation timeframes, as depicted in Fig. 13. The larger the project, the more prone the project team may be to schedule, cost, and resource estimation errors. Use of a formal management control structure and project management tools can help in understanding and communicating project complexity, priorities, and variables, leading to better planning and decision making from software acquisition through deployment.

8.1.3.1 The time required by laboratory personnel to implement fully an informatics system and gain the financial benefit is frequently underestimated. The underestimation of implementation time, in particular, is much more severe in large installations.

8.1.3.2 Laboratory informatics systems implementation, as with most significant IT projects, requires a long-term commitment from various groups to be successful. This includes ownership and support from the user community management coupled with effective delivery of the IT components of the project from the IT group. This IT group may be internal to the specific company or may include outside consultants/third parties.

8.1.4 *Keys to Successful Laboratory Informatics Projects:*

8.1.4.1 Obtain commitment from the user community and top management, beginning with formation of a project team comprised of a project owner/advocate from senior management, stakeholders, business analysts, subject matter experts, and key users, each with a predetermined resource allocation (for example, 50% or 20 h/week) over the life of the project. Larger projects will likely require business analysts with financial, technical, and/or IT backgrounds. A project steering committee may be useful for escalating decisions beyond the project team.

8.1.4.2 Assign a project manager with experience in managing complex projects and competing priorities.

8.1.4.3 Establish sound procurement processes, requirements, and selection criteria based on the organization's guiding directives and the business case driving system acquisition. Specifications should focus on the problems to be solved, rather than dictating or architecting the solution. IT requirements should be validated against the organization's technology standards and technology roadmap, rather than individual preferences or existing computing infrastructure. In estimating total cost of ownership, factor in costs for internal customization and support, savings through automation and operational improvements, projected product life cycle, add-on licensing costs, and software maintenance contracts.

8.1.4.4 Ensure that the necessary IT infrastructure (network, hardware, operating systems, antivirus software, and so forth, as applicable), is accounted for in the project plan, meets the minimum requirements of the target system, and is in place in advance of the system installation date.

8.1.4.5 Apply proven project management principles and tools, including development of a written project plan with tasks, objectives, deliverables, milestones, and ongoing project status reporting. Ensure that adequate work process evaluation is done before project startup to ensure that expectations and the endpoint are well-defined and understood by all. Consider "spiral," "agile," and other approaches that may be less deterministic or dependent on all user requirements being known in advance of startup. Weigh the advantages of iterative prototyping, particularly in high-priority areas of the operation.[18]

8.1.4.6 Avoid customization and change orders not adequately supported by a business case. Customization adds time and complexity to development and testing activities and may introduce additional sources of error. Carefully evaluate any potential warranty, technical support, and software maintenance (product upgrade) implications before making changes to the delivered system. Scope creep is subtle; utilize formal change control processes to approve any additions or changes to scope, no matter how small.

8.1.4.7 Provide project visibility across the organization, monitor and report on project success indicators (for example, budget, deliverables/milestones, resource utilization), and utilize stakeholder and user feedback to rebalance the project, if necessary.[19] Divide the project into manageable phases, if necessary, and periodically demonstrate progress against milestones in order to maintain momentum and management commitment. Communicate successes and reinforce the positive impact the system will have across the user community.

8.1.4.8 Provide adequate training to all resources engaged in the project in order to accelerate knowledge transfer and avoid delays or pushback from personnel in adopting the new system.

[17] *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*, Third Edition 2004, p. 165.

[18] Schwaber, K., *Agile Project Management with Scrum*, 2004, pp. 1-14.

[19] Verzuh, E., *The Fast Forward MBA in Project Management*, Third Edition 2008, pp. 221-241.

8.1.5 *Other Laboratory Informatics Project Considerations:*

8.1.5.1 Implementing a new system presents an opportunity to reexamine business processes and implement best practices concomitant with the new technology. Recognize that these additional goals will inevitably impact the resource and time requirements, and decide in advance whether the tradeoffs are justified. Avoid replicating outdated paper-based systems, retaining disconnected and disparate data sources (for example, spreadsheets/macros), or automating workflows that no longer make sense.

8.1.5.2 Systems, policies, and plans will be needed to protect the new informatics system assets. Examples include source control, data security, backup and archive procedures, and a disaster recovery plan.

8.1.5.3 Manual (paper-based) or standby systems should be established (and periodically tested) to maintain operational continuity in the event automated systems become temporarily unavailable.

8.1.5.4 Quantify the business value of the project (and yardstick for success) by comparing laboratory performance metrics (for example, samples processed per unit time, employee, and instrument, cost/test, quality defects/batch) before project startup and every three to twelve months after commissioning the new system.

8.1.6 *Alternatives to Laboratory Informatics Life Cycle Implementation:*

8.1.6.1 Customization to meet the requirements of large, complex, multi-disciplinary organizations may be inevitable, and following the system life cycle implementation approach produces the best results. Some informatics products are designed for specific industries or laboratory types, and may include preconfigured test methods, reports, and other templates used to expedite the implementation life cycle and minimize customization. In either case, it is important to understand how easily and quickly changes to the system can be made, and whether adequate resources (funding and personnel) exist to provide ongoing support for such changes. Smaller organizations, or those with more basic requirements, may benefit from alternatives to the formal techniques described in 8.2 through 8.5. Alternatives include *(1)* providing industry specific product demonstration scripts to compare off-the-shelf functionality with actual organizational workflows and processes; *(2)* evaluating products against the product guide checklists, such as the checklist in Appendix X1, *(3)* evaluating modular products that include basic functionality in a core system that can be expanded over time through add-on modules; and *(4)* adjusting laboratory work processes and procedures to make best use of selected commercial product functionality with little or no customization.

8.1.7 *Validation:*

8.1.7.1 The validation of a laboratory informatics solution is a mandatory step for regulated industries. Specific validation requirements exist for industries regulated by the FDA CFR Part 21, EPA (40 CFR 160) and FDA CFR Part 50, Appendices B, E, and K.

8.1.7.2 Validation of a laboratory informatics solution can add three to twelve months to the implementation time. Documentation plays an important role in the validation process. See IEEE 829, IEEE 1008, IEEE 1012, and IEEE 1028.

8.1.7.3 Reference GAMP 5 for additional detailed guidance on validating a laboratory informatics solution.

8.2 *Key Phases in the Laboratory Informatics System Life Cycle:*

8.2.1 *Phase 1—Project Initiation*—The purpose of this section is to outline the activities that occur during the project initiation phase of the system life cycle. The section contains three parts including project initiation and planning, developing a business case, and developing a quality plan. Using this section will provide the reader with a guideline to follow as they initiate a new informatics project.

8.2.2 *Developing a Business Case*—The decision to implement, upgrade, or replace an informatics system can be driven by many factors. Developing a business case to meet regulatory reporting or compliance requirements may be easier than a business case involving anticipated automation or quality improvements. Regardless, all business aspects of the new system need to be considered; for example, total resources (funding available, number and skills of laboratory staff), time requirements (for implementation, processing laboratory samples), short and long-range business plans, and key project objectives. Good cost-benefit analysis requires time, solid understanding of the laboratory environment, and careful analysis of the expected benefits. The cost-benefit components of inaction—not implementing the system—should also be addressed. An analysis of costs should consider the total cost of ownership (TCO), including the initial purchase costs, implementation (including anticipated customization) costs, and ongoing maintenance costs. Benefits are normally characterized as tangible (hard benefits that are easily calculated) or intangible (soft benefits that are recognized but more difficult to quantify). In Table 3, a list of potential benefits to assess for a typical laboratory informatics implementation is given. In fact, a financial value can be associated with most if not all benefits, a worthwhile exercise not only in justifying the decision but in prioritizing the implementation of features or modules. Document the assumptions associated with each calculation. It is important to understand that project success is not dependent solely on the system itself; the benefits result from hard work integrating the best of technology, people, and processes. Avoid creating unrealistic expectations if there is significant uncertainty in one or more of these areas. Disillusionment by management or end users often leads to project failure. Common sources of error in the cost-benefit equation include:

8.2.2.1 Assuming full conversion to a paperless organization in the initial phase of the implementation;

8.2.2.2 Failing to account for potential customization time and costs by assuming the system will meet all requirements as envisioned;

8.2.2.3 Failing to account for repeated iterations or corrections to deliverables by assuming requirements will be sufficiently known and specifications sufficiently detailed;

TABLE 3 Example Benefits Attributable to Laboratory Informatics

Tangible Benefit	Description/Comment
Laboratory throughput and capacity	Increase in the number of samples processed in the laboratory per unit time, analyst, department, and/or instrument.
Laboratory turn around	Decrease in sample processing time from start to finish.
Labor savings	Reduction in the number of analyst hours required to process samples and data.
Reduction in error rates	Automation systems reduce data entry, transcription, and calculation errors. Lower error rates improve processes by minimizing process waste/rework, including time spent reanalyzing samples and reprocessing data.
Reduction in time spent on laboratory investigations and quality inspection activities	Quality improvements allow more time to be spent in value-adding activities, and may allow for a reduction in the frequency of process inspection and data review steps.
Reduction in cycle time to release manufactured products	Integration with MRP/ERP systems enables release of product as soon as laboratory results are approved.
Reduction in customer service costs and time	Providing self-service, read-only access to sample status, test results, and other laboratory information eliminates end-user dependence on customer service personnel.
Reduction in time spent supporting audits	Ready access to electronic data, SOPs, audit trail documentation, and other quality records can significantly reduce the amount of time dedicated to audits.
Intangible/Other Benefits	**Description/Comment**
Better service management	Benefits will accrue from the ability to integrate information more closely with suppliers and clients.
Access to information/tools	End-user access to more data and better tools will improve self-service reporting and analytics. Data access will also facilitate routine and non-routine problem-solving.
Easier to achieve and demonstrate regulatory compliance	Improvements in work processes, standard operating procedures, and electronic record keeping will make it easier to enforce and demonstrate compliance with quality and regulatory requirements.
Earlier detection and correction of errors	Informatics technologies can alert users of out-of-control conditions or other problems that will trigger corrective actions as early as possible in the process.
Improved laboratory management	Better tools to enable more consistent workflow and management of laboratory operations.
Improved sample management	Sample tracking functionality can provide detailed knowledge on the status and location of all samples, reduce the likelihood of mislabeling or misplacing samples, and document sample traceability from collection through disposal.
Enforcement of Lean/Six Sigma practices, earlier intercepts of drifts in product quality	Closer coupling between the laboratory and manufacturing will provide quicker indication of quality trends and allow for near-real-time adjustments in manufacturing processes.
Improved customer satisfaction and competitiveness in the marketplace	Better quality data and services may improve customer satisfaction/confidence, the laboratory's reputation, corporate brand value, and overall competitiveness in the marketplace.

8.2.2.4 Forecasting productivity gains from an earlier date or at a higher adoption rate than may be reasonable;

8.2.2.5 Failing to account for impact on current laboratory productivity by underestimating staff time required to be involved in the implementation, train on the new system, and continue to use and maintain the system(s) being replaced;

8.2.2.6 Failing to have strategic planning in place (funds, personnel, and space) for expansion and eventual replacement of the system;

8.2.2.7 Failing to account for the time and effort needed to reengineer business processes that should not be automated by the new system;

8.2.2.8 Assuming the laboratory is at full capacity year-round or assuming current state capacity numbers in benefit calculations (failing to consider the increase in capacity that might be expected following implementation;

8.2.2.9 Failing to quantify accurately the differences in expected automation and quality improvements when comparing multiple options; and

8.2.2.10 Failing to factor in intangible benefits such as improved competitiveness, enhanced reputation, or preservation of product/corporate brand value.

8.2.3 *Project Initiation and Planning*—A project definition document should be developed that defines the scope of the informatics system early in the project. Fundamental questions that should be addressed include: *(1)* will all laboratories within a department or organization be included or just a few; *(2)* will more than one physical site be using the system; *(3)* are there any time boundaries on system implementation/operation; *(4)* are there any staffing or resource limitations or both; *(5)* are there any training/skills limitations; *(6)* are communication links to external computer systems required; *(7)* are there any IT limitations (hardware, connectivity, bandwidth); *(8)* are laboratory instruments or other devices going to be directly linked to the system; *(9)* does the laboratory use mostly paper records, Excel, mobile devices, or electronic notebooks; and *(10)* will the system be connected to external systems (for example, ERP, MES)?

8.2.4 *Quality Plan:*

8.2.4.1 *Quality Planning*—A sound, well thought out quality plan ensures a smooth, successful implementation and validation of a laboratory informatics system. A quality management system should include a quality policy and objectives, a quality manual, required documented procedures as well as documents needed to ensure effective planning, operation and control of processes, and required records. The documented procedures within the quality management system shall define how such a system will be implemented, validated, and maintained in a validated state during routine use and retirement of the system (system life cycle). In addition, the quality plan defines the required documents for a project such as user requirements document, functional specifications document, system design document, validation plan, and so forth.

8.3 *Phase 2—Requirements Analysis*—The purpose of this section is to outline the activities that occur during the requirements analysis phase of a system life cycle. The section contains five parts including: workflow analysis, business requirements, validation/quality planning, risk analysis, and system evaluation and selection. Using this section will provide the reader with a guideline to outline their informatics system requirements.

8.3.1 *Workflow Analysis—Current and Future State:*

8.3.1.1 *Model Current State Laboratory Practices*—Meet with informatics system users, end users, laboratory managers, and external users (customers) of laboratory information. Diagram sample work flow and information captured in the laboratory (see Section 6). The time required to model current laboratory practices can range from a few days to several months. Extended modeling may be counterproductive, if the time exceeds several weeks. Rapid prototyping may be more productive (see Guide E1340). There are many good reference materials and external consulting parties available to assist in the modeling process.

8.3.1.2 *Model Future State Laboratory Practices*—The future state for laboratory practices should be defined before system implementation/selection. Failure to perform this step may lead the user to automate laboratory processes that will subsequently change. First fix the process and then automate the optimum work flow. Laboratory informatics systems should not be used to set laboratory policy or procedures but may be used to enforce them. Invest the time to evaluate informatics solutions as part of the "Model Future State Laboratory Practices" exercise. Understanding informatics systems capabilities will enable users to define the best approach to the future state.

8.3.1.3 *Harmonize Process*—During the modeling process, find areas to harmonize within the laboratory, between laboratories, and across sites when possible. Harmonizing or standardizing processes where possible will ultimately simplify the system implementation and leverage the effort across the enterprise.

8.3.2 *Business Requirements Analysis:*

8.3.2.1 *High-level Business Objectives*—The high-level business objectives and strategies shall be understood and considered as a prerequisite for developing detailed business requirements for a laboratory informatics solution. The business requirements should be defined and documented as to what is needed and should be approved by key stakeholders of the business process. The business requirements should be realistic in terms of what can be expected of commercial systems or what can be expected for custom-developed systems based on known resources and their capabilities. This information is typically defined in a high-level project charter.

8.3.2.2 *Document-Specific Business Objectives*—Clearly defined and documented system requirements and business expectations will provide the backdrop for the project. Gain agreement from all parties who will be stakeholders in the project including laboratory personnel, management, quality oriented staff, information technology/services people, legal, documentation specialists, and engineering. Be certain that all parties understand the business objectives and metrics that will be used to test decisions and measure performance against these business objectives.

8.3.2.3 *Legal Issues*—Legal constraints on how your laboratory uses information need to be addressed. Regulatory requirements may necessitate specific system features like audit trails of system transactions, electronic signatures, unique user identities, system timeouts, or other requirements.

8.3.2.4 *Verification and Retention Issues*—Business requirements may require signed hard copies for all laboratory documents. Legal departments (if applicable) should be consulted on how you are planning to use the informatics system. Concepts of best available evidence for laboratory records need to be reviewed and understood by system users. Careful examination of regulations should be done to determine if there is a need for: *(1)* reported results to have provisions for two verifications, *(2)* reported results changed during on-line operations to generate an audit trail, and *(3)* provision that archived data and test/requester tables be loaded into present system for retrieval of information. Retention periods for both raw data and resident data should be evaluated and documented. Regular review of archived records should be made periodically to ensure that retrieval remains possible over the retention period defined. Management and security of informatics data and electronic records should be included within an organization's overall disaster recovery plan.

8.3.3 *Validation Planning*—The rationale of validation is to ensure that computerized systems perform according to predetermined specifications in an accurate, reliable, and repeatable manner. The purpose of the validation plan is to establish the process to be followed and the documentation needed to provide evidence that the system has been installed and is operating according to approved requirements, specifications, design, corporate policies, and regulatory and business needs. Validation planning is especially important for industries that are regulated by GxP (GMP, GLP, GCP).

8.3.4 *Risk Analysis*—There are several well-documented reference materials associated with risk assessment. (See, for example, ICH Quality Guideline Q9) Users should evaluate projects against their business objectives and the risk associated with the informatics project. Risk parameters include, but are not limited to, overall project risk, product risk based upon the impact that the new system will have on the product quality, people risk in the area of change management, and business risk. Business risk may include risk introduced by software customization.

8.3.5 *System Evaluation and Selection:*

8.3.5.1 *Request for Proposals (RFP)*—Issue a request for proposals (RFP) to prospective informatics systems vendors. The RFP should include a summary of your functional requirements, annual sample quantity, test complexity, process flows, sample work flow/model, and business rules to define your specific needs.

8.3.5.2 The laboratory informatics concept model and example RFP functions in this guide can be used to identify your requirements to prospective vendors. The examples can be tailored to match your laboratories' requirements. Time required to write and issue a RFP can range from a week to a month or more.

NOTE 2—Custom informatics solutions can be built in-house. Custom-built solutions are recommended only if unique requirements demand it and there is an adequate budget to support the coding, testing, validation and management, support and updating of the system. The business case for building and maintaining a solution in-house needs to be thoroughly vetted against the alternative of purchasing and maintaining a commercial system, which may be more cost-effective and less risky. The functions in commercial informatics systems need to be compared to your specific

laboratory functional requirements.

8.3.5.3 *Evaluation and Selection*—Quotations received from software vendors should be evaluated against the functional requirements document. Objective judgments of the advantages and disadvantages of each product should be made. Weights can be assigned to each system function for complex systems. Refer to laboratory informatics checklist in Appendix X1 as starting point and add your own functional requirements. The people who will be interacting with the system should take an active role in the evaluation and selection steps. Site visits to installed systems are recommended. See section on laboratory informatics database technology and hardware platforms for additional issues. Some guidelines for evaluating and selecting an informatics system include:

(1) Verifying that data structures (profiles, tests, calculations, specifications, and related information), information types (numeric, text, date/time, attached documents, and so forth), and the underlying informatics technology closely match your current information structures, data requirements, and work flows;

(2) Assuring that the system is sufficiently flexible to modify the statuses needed to monitor and manage work in your laboratory;

(3) Prioritizing selection criteria based primarily on required functionality as supported by an established business case, rather than individual user biases or preferences. Hardware should be a secondary priority unless specific hardware shall be leveraged;

(4) Assessing whether the informatics solution is based on a modern, commercial database management system or database toolbox that is reliable, effective, and supported external to your laboratory informatics vendor (this is especially true if there are plans to significantly customize the laboratory informatics system in the future). If dictated by the business requirements, the database should permit the end user to add/modify fields, indexes, relationships, tables, and codes. Proprietary laboratory informatics database management systems may be required to meet specific performance requirements. Portability of data is a key factor in selecting a laboratory informatics solution, including compatibility with industry standards for accessing data;

(5) Carefully evaluate technology and market leaders specializing in your analytical areas of interest, which may provide base configurations, templates, and best practices to help expedite the configuration; and

(6) Assessing whether the solution permits third-party tools to be used for report generation, export, import, and links to external systems, security, and monitoring beyond functionality built directly into the system.

8.3.5.4 *Purchase*—The purchase contract shall contain terms and conditions required by the end users and suppliers. Typical items include specifications, delivery dates, acceptance testing, payment schedules, source code escrow provisions, software support and update policies, required documentation, training, installation, warranties, and listing of all required hardware and software. Terms for licenses and third-party software, if applicable, should also be addressed. Purchase orders should reference the contract when each order is placed, allowing the user to stage payments for licenses and services over the delivery schedule for the system.

8.3.6 *Vendor Demonstrations:*

8.3.6.1 You may choose to include a scripted vendor demonstration as part of the selection process. Use of a script may allow the laboratory to more easily evaluate and compare different systems, and to assess their ability to meet the stated requirements of the laboratory with minimal customization. The demonstration should be planned in advance, with at least two weeks prior notice to the vendor. Provide the vendor representative examples of sample types and test methods, along with a set of scenarios and expected results that address areas of functionality critical to the successful implementation of the system. Typical areas for demonstration include the administrative tools and functions for configuring and customizing the system; the sample receiving process; complex traceability issues such as tracking of subsamples or aliquots; test method calculations or limit checking; automatic generation of samples and assignment of tests for skip lot testing; or complex retest/rescheduling logic. Allow sufficient time for the vendor to show how the functionality was configured or customized, to demonstrate unanticipated features and alternative solutions, and to describe how their technology is otherwise differentiated in the market.

8.4 *Phase 3—System Design:*

8.4.1 *Functional Requirements Analysis:*

8.4.1.1 Depending on the system development life cycle being followed, functional requirements may be defined in a separate document from user (business) requirements. User requirements describe in business language, what the system is required to do to support the business process. Functional requirements describe in the language of the functionality of the system, how the system will satisfy the business requirements. In other words, functional requirements are the translation of business requirements into application-specific language. Functional requirements should be specific, measurable and realistic to ensure testing can easily confirm that requirements have been satisfied.

8.4.1.2 Where business and functional requirements are defined in separate documents, industry regulations may dictate that they be linked using a traceability matrix to provide complete traceability between business and functional requirements.

8.4.1.3 Functional requirements may be documented in the form of a checklist of major features and functions of the system that will be configured and used (see the laboratory informatics system guide checklist in Appendix X1). The Laboratory Informatics System Functions Map (Fig. 3) can be used as a starting point in developing a list of laboratory informatics system functions. See IEEE 830 for a general guide on developing software requirements. Specific hardware and software standards in place at a particular laboratory or company may also need to be adhered to and, therefore, specified in functional requirements.

8.4.1.4 Functional requirements analysis is normally performed after the selection of the laboratory informatics system is complete. The selection will have been made based upon the vendor's ability to meet the business requirements through

analyzing how the selected system will meet the users' needs. The output of the process is a Functional Requirements Specification document. This document describes in detail the selected system's functions. Defining the functional requirements necessitates a thorough understanding of the business process(es), user requirements and selected system capabilities. Functional requirements should include the following areas: business requirements, hardware, software, user interface, system performance, availability, system interfaces, security, regulatory, system management, documentation, help, and training.

8.4.1.5 Functional requirements should be ranked in order of importance (for example, critical, important, nice to have) to facilitate decisions on whether certain functions shall be implemented in initial phases or may be delayed until later phases.

8.4.1.6 Rapid prototyping development techniques may be used to assist users and the development team in elaborating high-level functional requirements into a detailed set of functional specifications. When working with commercial off-the-shelf products, this process is also beneficial in helping constrain user expectations and system scope with the out-of-the-box capabilities if avoiding excess configuration or customization is desired.

8.4.1.7 Development of detailed functional requirements may take anywhere from five to twenty days or more excluding prototyping time and review/approval cycles.

8.4.2 *System Design Document:*

8.4.2.1 The resulting deliverable is the system design document (SDD) that details the system design specifications. The SDD should provide enough information to build and configure the system software and network architecture.

8.4.2.2 During this phase, users may again be interviewed to get specific details of process flows or elaborate on requirements for a definable portion of the business process. Process flows are constructed in layers so that an overview of the system processes are understood including the system interfaces as well as the details of specific area workflows so that adequate design specifications are documented for configuration/coding clarity.

8.4.2.3 When using prototyping techniques, specific information about how the system will be used and functions required by the users will be gathered and listed in a high-level system design document that will be used to guide the prototyping.

8.4.2.4 The system architecture as well as hardware and software may be defined at this stage as well. This could be defined in one section of the system design document or in a separate system architecture specification document.

8.4.2.5 Development of system designs may take anywhere from five to fifty days or more excluding prototyping time and review/approval cycles. The more design that is afforded up front in a project the smoother the configuration/coding will proceed.

8.4.2.6 When implementing a commercial off-the-shelf laboratory informatics system, a system configuration document may be written in place of a system design document. This document is generally written after the configuration of the system is complete. It details the various configuration choices and settings that were made during the configuration phase. Documentation regarding the design of such a laboratory informatics system is usually available from the vendor.

8.4.3 *Unit and Integration Test Plans:*

8.4.3.1 An approach for testing the system should be defined before the build/configuration activities start. Development testing for custom software code normally includes unit, integration, and system testing of the configured system modules, interfaces, and any custom developed modules. The test plan should include topics such as scope, test strategy, responsibilities, test preparation, test procedures (including deviation management), and definition of limits and ranges.

8.4.3.2 Development of unit and integration test plans may take anywhere from two to ten days or more excluding review and approval cycles.

8.5 *Phase 4—Build/Configure:*

8.5.1 *System Configuration and Development:*

8.5.1.1 In this phase, the system software is configured, interfaces are configured or developed, any required customizations coded, hardware assembled, and the components are integrated into a complete system based on the design specifications.

8.5.1.2 Configuration involves using the administrative and master data functions provided in the commercial software to prepare the system for use. These activities are normally accomplished by setting values, selection of check boxes, filling-in forms or tables of values, or other similar activities that define and control how base system functions perform. Commonly configured items include defining sample types, sample registration forms or result entry forms, defining approval types, roles, and responsibilities of users.

8.5.1.3 Customization is most commonly defined as software development activities that involve writing procedural programming code in the laboratory informatics system vendor's proprietary development language or other third-party languages. Furthermore, customization may alter the way base system functions were intended to be used or add new functions not present in the vendor's base product. Customizations may be built to improve efficiency or quality by automating steps or actions normally executed by users in the system. Examples of customization are: *(1)* dynamic update of customer limits; *(2)* material inventory in the laboratory informatics system's database through integration with a separate client database system to determine the appropriate customers for manufactured products; *(3)* periodic update of quality results to external enterprise database to determine quality of raw materials and finished products; and *(4)* interfacing with laboratory devices for automatic data.

8.5.1.4 Configuration can normally be accomplished quickly and effectively through the administrative functions provided. Coming to a decision on how to best configure functionality make take several days to several weeks of working through options and assessing their impact on other system functions. Customization can take several days to several months to design, code, and test depending on the complexity of the required functionality.

8.5.1.5 It is important to understand the system's fundamental design with respect to extensibility. If the software includes an Application Programming Interface (API) or other means by which the product can be customized without compromising ongoing product warranty or support, the impact on project scope, testing/validation, and maintenance may be minimal. Modifying core system code or table structures, or procedural programming through a third-party language or Integrated Development Environment (IDE) may have more far-reaching consequences.

8.5.1.6 There are many methodologies for system configuration, development and testing. ISO/IEC 12207 can adequately explain the different approaches to software development. The approaches range from phased implementation to rapid prototyping.

8.5.1.7 Rapid development characterized by iterations of the design, build, and test activities supported by a cross-functional team (representation from business, IT, and quality) has proven an effective methodology and is frequently used today.

8.5.1.8 The rapid prototyping is typically planned to be accomplished in three to five iterations with each iteration taking anywhere from two weeks to two months or more.

8.5.1.9 In prototyping, an initial high-level design is developed that should be used to guide the prototyping of the system. Through iterations of design, build, and test, further details regarding requirements and system design are elaborated and may be documented in a system design specification. The detailed configuration parameters and detailed design specifications are updated simultaneously but may not be formally approved until the close of the final iteration.

8.5.1.10 Requirements are divided into logical groupings to form the development or prototype units. Functional requirements should be met by configuration of the laboratory informatics system or custom code where necessary.

8.5.1.11 Custom code modules should be developed using quality development standards. This includes establishing common standards for commenting code, defining variables, any naming conventions for variables or modules, indenting, and so forth. Standards should be established and used by the entire development team. A technical team lead or a senior developer should review code for adherence to these standards. Standards should address the following topics: modules should have descriptive program headers including information such as revision date, (if appropriate, build number), programmer name, system name (revision number if appropriate), module name, module purpose, any required syntaxes for external references (inputs or outputs) to/from the module, and any unique considerations for integration. A change history (names, dates, brief descriptions of changes) should be included in program headers. Code should be indented and include sufficient comments to enable other programmers to understand easily and work with the code.

8.5.1.12 At the end of each build iteration, before the prototype review, the code and development for the current prototype scope is frozen. The functionality in the prototype should be demonstrated to the users for their review. Any change/correction requests should be documented using a change control process in which requests are analyzed and submitted to the development team for inclusion in the final system build.

8.5.1.13 Development of system configuration and customizations may take anywhere from couple of weeks to several months or more including prototyping time.

8.5.2 *Unit, Integration/System Testing, Performance Testing:*

8.5.2.1 At the conclusion of system configuration or prototyping, the final system may be built and undergo unit and integration testing prior to the start of formal validation in regulated environments. Unit and integration testing are performed in the development environment by the development team. Each individual development unit is tested separately against defined design parameters in the system design specification. Integration testing is also performed by the development team on functionality provided by a cohesive group of units. In this phase, the development team logically combines individual development units and tests the resulting system as an integral unit. Integration testing will also test any interfaces between the laboratory informatics system and other laboratory or enterprise systems. Performance testing will be done in the development or QA environment against a set performance benchmark. This testing will be done by developers/testers using standard tools.

8.5.2.2 Unit and integration test scripts should be developed by the development team and should be reviewed and approved prior to execution. A performance testing script should be developed by developers/testers and will have to be reviewed against the standard set of benchmarks as defined in the business requirement. Having test scripts for a particular development unit/module developed and executed by a developer or test team member who did not develop the code for that unit/module is very effective in identifying errors and helping produce a robust system. Any anomalies encountered during testing should be documented and change control used to document software defects, proposed resolutions and then the failed test may be re-executed after corrections have been made.

8.6 *Phase 5—Test/Commission:*

8.6.1 *Hardware and Software Installation/Qualification:*

8.6.1.1 *Validation*—The validation of the laboratory informatics system is a mandatory step for regulated industries. Specific validation requirements exist for industries regulated by agencies such as the FDA, EPA, and NRC. Properly managed execution of validation principles that represent the use of best practices can save time, resources, materials and expenses in the long run. Traditional validation methodologies such as defined in GAMP can add three to twelve months to the implementation time of a laboratory informatics system. The application of intended use methodologies or a risk-based approach can reduce time and cost within the regulated framework. Documentation plays an important role in the validation process for a laboratory informatics system. Refer to GAMP and/or Guide E2066, IEEE 829, IEEE 1012, and IEEE 1028.

8.6.1.2 *Documentation*—Documentation includes manuals supplied by the vendor and user-developed documents. Examples of vendor-supplied documentation include user operational manuals, technical reference manuals, validation manuals, QC documentation, and vendor staff curriculum vitae. User-developed documents include all standard operating procedures (SOPs), training documents, change control forms, definitions, acceptance-testing records, problem report logs, backup and recovery logs, audit reports, and security records. See IEEE 1063.

8.6.1.3 Standard operating procedures (SOP), as a requirement for a holistic approach to validation, include, but are not limited to: Back-up and recovery SOP (include testing of systems and files on a regular basis). Use SOP defining how users use the system and what type of information is being entered into the system as well as the data sources; system administration SOP defining governance of tasks such as assignment of security within the software, system security, logical security and physical security; and change control SOP defining not only what steps are followed to make changes to the system but also include risk assessment of the changes and the impact to the system.

8.6.1.4 *Laboratory Informatics System Staffing Requirements*—Staffing requirements will vary depending on the size of the laboratory, number of users supported, and the complexity of the laboratory informatics system implementation. Additional resources will be required during the initial laboratory informatics system implementation for analysis, design, configuration, and testing tasks. Resources will also need to be dedicated to system administration and support for as long as the system is in production use. These resources may not need to be full time depending on the maturity of the laboratory informatics system. Many laboratories engage resources in ongoing system support providing enhancements including additional functionality and reports. The cost of these resources can be supported by the benefits achieved from the additional functionality. Laboratory informatics system support can be provided either by laboratory or information technology staff. The ideal candidate combines both laboratory and computer experience. Many companies have been successful in retraining existing laboratory personnel to acquire computer skills. laboratory informatics system support can also be outsourced.

8.6.1.5 *Training*—End-user and system manager training require appropriate planning and continued support. Training covers all aspects of laboratory informatics system operation from user training on how to perform sample registration, enter results and report results, to system manager training on how to maintain complex computer systems. Training is often tailored to the roles defined in the system that determine what specific functions each user can access. Training documents maintained for each user can include personnel backgrounds, education, qualifications, job experience, job descriptions, and formal testing of specific system functions. Training certification can be maintained in some laboratory informatics systems.

8.6.1.6 *User Acceptance Testing*—Before a laboratory informatics system is released for production use, all or some of the intended users are given an opportunity to evaluate whether the system does indeed support their daily activities and whether none of the users' daily tasks are impeded by the system. Scripted testing can help verify proper operation; unscripted testing may help uncover missed requirements.

8.6.1.7 *Data Migration*—Data migration requires a carefully thought-out plan to assess the transfer of data and metadata from one system to another. The plan should account for synchronization of field types, field length, field mapping, and manual verification with a sampling schedule. Migrated data can also be considered part of static data loading (see 8.6.2).

8.6.1.8 Laboratory informatics systems are capable of maintaining information on a broad range of business and laboratory data required for the effective operation of the laboratory. Laboratory informatics systems contain data that not only reflect the current operation state of the laboratory but also historical information on past performance and events. Where a laboratory informatics system is introduced into an environment in which an equivalent system has not previously been deployed, much of the information typically managed in the laboratory informatics system will exist in the form of paper documentation or disparate electronic sources such as documents, spreadsheets or specialized databases. When implementing the laboratory informatics system, some of this data will provide the basis for configuring the system. Static data are always loaded into the laboratory informatics system as part of the system deployment lifecycle. The decision on how to deal with historical dynamic data should be evaluated on the basis of risk. Appropriate strategies for dealing with this data include migration, preservation, and archival. Where an existing laboratory informatics system is being replaced with a new solution, it may be possible to migrate data from the source laboratory informatics system to the new target laboratory informatics system. In such cases, the following steps should be considered: source data analysis, target database configuration, source to target mapping, data migration workflow planning, migration piloting and process validation, data migration, and data verification. Laboratory informatics systems often provide embedded or commercial tools to assist with data load and data migration processes.

8.6.2 *Static (Master) Data Loading:*

8.6.2.1 *Loading of Test, Calculation, Specification, and Other Static (Master) Information*—The loading of a laboratory's tests, calculations, specifications, and other static information into the laboratory informatics system's database is usually the most time-consuming step in implementing a laboratory informatics system. A large laboratory with hundreds of tests, calculations, and specifications can spend 6 to 24 plus months on entering and verifying master data. Smaller laboratories with fewer tests, calculations, and specifications can reduce the implementation time to one to six months. The ability to migrate data using automation (if it is possible) can greatly reduce costs in terms of time, transcription errors, and verification. (See 8.6.1.7.) This area of planning is consistently the least clearly understood or planned area in laboratory informatics system implementation. The failure to quantify clearly the costs and time associated with this single laboratory informatics system implementation phase can place the entire

project at risk. The total cost in person-hours required to enter the information can exceed the total cost of hardware and software. Detailed planning and prototyping is recommended to maximize efficiency in this area. Each laboratory needs to address this task on a case-by-case basis.

8.6.3 *Rollout:*

8.6.3.1 Rollout can occur in all laboratories and all modules at once or in a phased approach. For smaller systems, the first approach works well since the number of users are manageable. For larger installations, a phased approach may be a better way to go since the limiting step is training resources and supporting new users on the system immediately after going live. Other considerations are system performance, initial end-user acceptance, system tuning, and adjustment. System performance contributes greatly to the initial reactions for end-user acceptance. If the end users find that the system is sluggish they will be unhappy and slow to adopt the technology. Phasing facilitates managing the rollout. User surveys and positive posting of the results can contribute to better acceptance. This will also help the system administrators in obtaining information for making adjustments.

8.6.3.2 Rollout also requires planning for future issues with the system, including tracking those issues, escalation to vendor customer support, request for bug fixes/enhancements (for both the project and core product), system restores, and data restores. A business continuity plan may help address future issues that prevent continued operation of the system.

8.7 *Phase 6—Operation and Maintenance*—Operation and maintenance tasks include data backup, data recovery, various database management and optimization tasks, user account maintenance, resolution of user issues with the system via a support process, and general administration such as service contracts administration and software/hardware maintenance and upgrade.

8.7.1 *Laboratory Informatics Staff and Organizational Placement*—A laboratory with a staff of around 50 will generally require a minimum of one full-time person dedicated to the maintenance of the laboratory informatics system. Larger laboratories may have two to five full time staff supporting the laboratory informatics systems and laboratory automation. The laboratory informatics system staff generally supports laboratory automation including LIMS, CDS, and other data acquisition systems and robotics. Organizations with data-processing departments shall decide where to locate the laboratory informatics system support staff, and options may include being located in the laboratory organization in the IT organization, in a technical services organization, or in the data processing organization, or a combination thereof. Factors to be taken into account, when deciding how best to support the laboratory informatics system, should include the accessibility and the responsiveness of the laboratory informatics system support staff to the laboratory staff. Small laboratories may absorb the laboratory informatics system staff functions with the existing laboratory staff. The computer and system skills required of the laboratory informatics system staff vary with the technology used. Systems implemented within centralized data centers generally require specialized staff resources with skills supporting those architectures. The ideal candidates for laboratory informatics system staff include personnel with both laboratory and computer experience. Laboratories have been successful in retraining existing laboratory personnel to acquire the appropriate computer skills.

8.7.2 *Security*—Policies and procedures need to be established to document the users' access to data, and privileges to update, insert, and delete data. Laboratory informatics system privileges should be assigned in terms of business needs, assuring data integrity, QA/QC considerations, business ethics, and customer confidence in privacy and safety of data. A procedure to document changes in users' privileges should be established covering the full lifecycle of the user. All changes to data within the laboratory informatics system should be subject to audit trail recording within the system at the time the changes are made, and this is especially so where regulatory requirements mandate it. Certain transactions within the laboratory informatics system may be subject to electronic signature approval dependent upon the regulatory requirements the system is operating within.

8.7.3 *Backup*—A backup policy needs to be established. Policy needs to contain type of backup(s) and frequencies of backup(s). Careful consideration should be given to the tolerance for data loss.

8.7.4 *Disaster Recovery*—A disaster recovery procedure should be established. Disaster recovery exercises should be conducted at a specified frequency.

8.7.5 *Data Archive*—The archive of laboratory informatics system data may be performed periodically to manage system storage space and performance.

8.7.6 *High Availability*—Dependent upon the importance of the data and the necessity to potentially require the laboratory informatics system to be available 24/7 it may be necessary to ensure the system is built on an architecture which provides the capability for the system to be continuously available and also tolerate all users actively using the laboratory informatics system at the same time.

8.7.7 *System Administration*—Special system software, audit trails, and laboratory informatics system reports are used to monitor the fidelity of system data and information. New instruments may be connected to the laboratory informatics system for transferring information. Links to external systems are maintained and serviced. Preventive maintenance tasks are performed per a predefined schedule. Repairs are conducted on failed hardware units. Software support is conducted with the laboratory informatics system vendor via telephone, email, and websites.

8.7.8 *Regulatory Requirements*—Laboratories falling under a country's regulations should be compliant with that country's regulations and guidelines.

8.7.9 *Maintenance and Support*—Commercial laboratory informatics systems generally have maintenance agreements and services that cover technical support with varying degrees of service. The service agreements can include written or implied provisions for software upgrades and training and clear definitions of both user and vendor support expectations for the life of the arrangement. The service agreement should spell out how disagreements over service will be mediated and should be made a part of the contract with the laboratory informatics

system vendor. Arrangements for escrow control of the source code may be made as part of the overall support and maintenance for the laboratory informatics system.

8.7.10 *Change Control*—Change control/configuration management plays an important role during laboratory informatics system operations. Changes in hardware, software, laboratory staff, and laboratory environment need to be carefully monitored and controlled. Examples of activities that trigger change control include: the installation of product updates provided by the software vendor and customizations made by the system support staff. Examples of change control activities include: testing of system changes before deployment into the production system and training of users on new and changed features. Change control procedures should be in place at the start of implementation. Change control procedures should define persons authorized to approve changes (hardware and software). Standard forms should be developed to track and manage changes. Alternatively, commercially available change control software can be purchased. Customizations to the code should be documented and approved by a formal process. Customizations should include a scope of work detailing the business needs for the customization, the business rules the code should be compliant with, and detailed functional requirements. Information tracked during changes should include requirements to be met before approval of changes, revision numbers for all the code undergoing change, responsibilities for documenting testing, approving of changed versions, and moving changed versions to the production environment.

8.8 *Phase 7—System Retirement (Replacement, Archive):*

8.8.1 *Planning*—The retirement of an application needs to be carefully planned to avoid unintentional disruption to the business now or in the future. A comprehensive plan addresses the following elements: verification that business functions are no longer needed or will be available in a different application; identification of all users and dependent applications; inventory of hardware and software; a timeline for discontinuing or disabling functionality; exporting data so that it can be imported into a new application; archival of data in electronic or human-readable form; and migration of data into a new application. The plan needs to be communicated to users and other parties that may be impacted by the retirement.

8.8.2 *Verification of Obsolescence*—This step is relevant in cases in which an application is not being replaced or is being replaced by an application with a different functional footprint. In the case of replacement, early training on the new system may help identify any gaps in functionality. In the case of an application that is governed by SOPs, early drafting of new SOPs may help identify functions or features that are still needed after retirement.

8.8.3 *Users and Dependent Applications*—All users of the application and all owners of other applications that depend on it need to be identified so that they can be informed of the planned retirement. This can be difficult for applications that do not require authentication, do not log access, or are installed on multiple computers without connection to a central server or database.

8.8.4 *Inventory of Hardware and Software*—A common objective of a retirement is cost savings. Hardware and third-party software used by an application may be able to be redeployed or retired altogether. This includes hardware and software that may be dedicated to nonproduction environments. Maintenance contracts may be targeted for cancellation.

8.8.5 *Change Management*—Retirement often encompasses many steps that need to be performed in a proper sequence to avoid disruption to the business. A detailed timeline needs to be created, communicated, and managed. All parties need to be kept informed of ongoing progress and reminded of upcoming events.

8.8.6 *Data Archival*—Laboratory data will need to be maintained for at least business and possibly regulatory reasons. Retention schedules will need to be adhered to, and these can vary greatly dependent upon the industry, company, and any regulatory requirements. With the advances in technology and virtualization, companies may explore converting to flat tables for future retrieval. Data can be maintained in on-line read-only state with minimal infrastructure cost.

8.8.6.1 Other options include exporting data to a third-party provider to archive it and then retrieve when needed again. There are costs associated with this option and the risk of the vendor going out of business; there may also be limitations with retrieving the data in a timely manner.

8.8.6.2 If data is to be stored in human-readable form, one option will be to print the necessary data to paper and archive it in a secure storage repository. There will be time and effort associated with retrieving the information if needed in the future. A more modern option may be to print the data to PDF instead of to paper.

8.8.7 *Migration of Data into a new Application*—When replacing an application with a new one, opportunity exists to leverage new capabilities within the solution and to move the existing laboratory data into the new application as part of the implementation project. When migrating data, business rules need to be established and applied in the requirements gathering phase relating to how much historical data and which data is to be migrated to the new application.

8.8.7.1 A company may make the decision to not migrate any data and start new with an empty database; if this is the scenario, then a strategy should be formed on how to process out the operational data and archive the historical data. (See 8.8.6.) Initially, this strategic direction may cause anxiety with the users though benefits can be realized early in the life cycle. With each passing year, the impact reduces as the need to access older historical data will lessen.

8.8.7.2 If the decision is to migrate data, then rules or policies shall be established by the organization and should take into consideration any compliance, risk management, legal, IT, and business requirements regarding how much and which data needs to be migrated to the new laboratory informatics system. The defining of these rules will be influenced by how the historical data will be used. If historical data is to be used in reporting, the organization may have additional challenges with any necessary data conversion and/or report enhancements. Organizations should also investigate whether gaps will be created with other business systems as a result of

migrating historical data. Many vendors offer data migration tools to minimize the effort and expense, but ultimately, the organization needs to define the migration business requirements and risks.

9. Lean Laboratory and Continuous Improvement Concepts within Laboratory Informatics

9.1 Laboratory informatics can be used to support and facilitate lean concept implementation, resulting in significant benefits when they are integrated successfully. Lean concepts can be applied in laboratories to improve productivity, quality, and efficiency while reducing costs. Lean concepts most likely to be facilitated with laboratory informatics include: workload leveling and flow, visual management, continuous process improvement, and waste reduction. Each of these concepts is briefly described below. Reference Section E-15 in Fig. 3.

9.2 *Workload Leveling and Flow:*

9.2.1 Leveling strategies are used to balance the incoming workload and maintain a consistent work flow to make the best use of the resources available in the laboratory. Leveling is the smoothing of the variability of the incoming demand for work by ensuring that each work day has a consistent workload. Continuous flow concepts keep the work moving through the laboratory processes while minimizing queuing or backlog between steps (examples of areas in which workload leveling and flow can be applied include functions C-1, C-2, C-3, C-4, C-5, and E-14 of the Laboratory Informatics Functions Map in Fig. 3).

9.2.2 Laboratory informatics systems contain the data needed to develop the workload leveling and flow strategies: expected average incoming workload demand, expected turnaround times for sample testing, actual testing times, optimal testing batch sizes, required sample result due dates by customer, current amount of work in the laboratory, and available staff and equipment.

9.2.3 Laboratory informatics can be used to automate the release of work into the laboratory based on the workload leveling strategy for each laboratory, thereby minimizing the scheduling and planning effort required to level the daily workload.

9.3 *Visual Management:*

9.3.1 Visual management implementation allows quick assessment of the work flow processes at strategic points and is meant to provide the opportunity to indicate whether a process is working optimally (examples of areas where visual management can be applied include functions C-3, C-4, and many of the E functions of the Laboratory Informatics Functions Map in Fig. 3). Laboratory informatics can support this lean concept by visually displaying summarized data and compiling all needed information into one location to allow all users to quickly identify workload requirements as well as where review and action is required. Laboratory workflows can also be visually displayed by laboratory informatics systems showing sample queues, sample locations, test status, samples/tests ready for review, and areas that need attention (that is, laboratory investigations).

9.3.2 Color coding, symbols, and icons that are easily understood and recognizable can be used to allow users to understand statuses and identify issues quickly. For example, dashboards can have colored gauges to represent the percent of work completed on time, the current turnaround time against a six-month average, or the amount of scheduled work as a percentage of capacity.

9.3.3 Visual management dash boards can be used to provide real time electronic updates on sample status for customers of the laboratory.

9.3.4 Other examples include real time control charts showing key performance indicators versus their warning and control limits, graphs of error rates pinpointing areas of opportunity for improvement, pop-up alerts can indicate imminent deadlines, and so forth.

9.4 *Continuous Process Improvement:*

9.4.1 Continuous process improvement tools are used to map actual work flow and can help identify potential failure points or places where consolidation or separation of steps would be beneficial (examples of areas where continuous process improvement can be applied include many functions but in particular C-3, E-5, E-13 of the Laboratory Informatics Functions Map in Fig. 3). A key to success with continuous process improvement is to understand the work flow and identify waste at the ground level of laboratory processes, with subsequent implementation of small changes continuously rather than major changes all at once.

9.4.2 Laboratory informatics can support this by rendering data onto dashboards and reports, and into control charts and production graphs: error rates, turn-around times, inventory control, and so forth. These can be used to identify bottlenecks and vulnerable steps in the processes, and also to monitor the effectiveness of improvements. The data in the laboratory informatics systems can be used to measure and monitor key performance indicators before and after implementation of changes, and inform future decisions.

9.5 *Waste Reduction*—Waste reduction as a concept covers many areas, all related by the goal to decrease the amount of effort or time that does not add value to the product from the customer's point of view. Continuous process improvement can be used to reduce wastes in laboratory processes. Some key opportunities for waste reduction within laboratories are planning and scheduling work, reviewing and approving data, filing paperwork, documenting, and data entry or transcription. The following are examples of waste reduction strategies that can result in significant benefits for a laboratory:

9.5.1 Review by exception is a waste reduction strategy that uses laboratory informatics systems to monitor key process parameters of mature, highly repeatable batch processes and to evaluate them against specifications that have been configured and validated within the laboratory informatics system. Visual management tools such as color coding or symbols allow out-of-specification results identified by the laboratory informatics system to be flagged for laboratory analyst/supervisor review, while in specification results are confirmed by the system and do not proceed to a manual review (examples of areas where review by exception can be applied include functions C-4, E-9 of the Laboratory Informatics Functions Map in Fig. 3). Examples of laboratory transactions that can utilize review by exception concepts include: fit for use of

equipment, raw materials, and consumables; training records; deviations from standard operating procedures; and so forth. Evaluation of only the failing parameters reduces the time spent reviewing and approving, resulting in a faster time to release, lower cost, and higher through-put.

9.5.2 Automation is another waste reduction approach to reduce time spent on processes in which there are set formulae, rules, or steps by using the laboratory informatics system to perform these types of transactions instead of a laboratory analyst (examples of areas where automation can be applied include functions E-6, C-6 of the Laboratory Informatics Functions Map in Fig. 3). Examples of these processes within laboratory informatics are: calculations; batching of samples; parsing of data from instruments, spreadsheets, and tracking systems; passing or sharing of information from one system to another; and data compilation. Automation of these processes removes the need for the secondary manual review of accuracy allowing for more productive work to occur.

9.5.3 Paperless laboratory processes are waste reduction tactics to reduce the amount of activities executed on paper. Paper-based transactions can be error prone and require manual reviews to confirm accuracy, are difficult to search for data and information when there are investigations, and require physical handoffs that can increase wait times in laboratory processes. In addition, the paper itself creates wasteful non-value added tasks, as the paper shall be purchased, handled, filed, stored, and destroyed (examples of areas where paperless processes can be applied include functions E-1, E-6, E-8, E-13 of the Laboratory Informatics Functions Map in Fig. 3). Paperless laboratory processes have a high potential of reducing non-value added steps, a key factor in implementing lean. Laboratory informatics are a critical component of paperless laboratory processes, as they are able to display, store, and transmit information electronically. Laboratory informatics systems are also highly searchable electronic storage systems that allow for rapid retrieval of stored items, or links to files stored in the informatics system. Going paperless with laboratory informatics includes activities like: capture of data directly from a balance, pH meter, instrument, and so forth; links between systems to allow the sharing of one document without having it stored a second time; and covers the implementation of capturing logbook or notebook entries when a touch-screen or keyboard is used instead of a pen.

9.5.4 Mobile devices such as smartphones and tablet PCs that are able to receive notifications from an informatics system regarding imminent or actual issues or that are able to access inventory applications, dashboards, reports, and so forth also support the lean concept of waste reduction (examples of areas where mobile devices can be applied include functions E-5, E-7, E-8, E-10 of the Laboratory Informatics Functions Map in Fig. 3). With such easily accessed information available, decisions regarding remedial or corrective action can be made in a timely fashion resulting in a quicker resolution of issues and faster turn-around and greater productivity.

9.5.5 Streamlining laboratory informatics support functions is important to both the initial implementation as well as keeping support costs low. Examples include use of leveling, flow and standard work, and visual management concepts for administrative and support functions like master data maintenance, help desk support calls, change control monitoring, and user account maintenance.

9.5.6 There are many ways in which laboratory informatics can support the implementation of lean concepts. The informatics systems contain the data needed to summarize and evaluate performance markers and processes. They are responsible for handling the import and export of data, and for the controlled access to those data. Laboratory informatics systems are key elements in the improvement of productivity and efficiency, and to the reduction of time and effort spent processing laboratory work, decision-making, and improving laboratory performance.

10. Keywords

10.1 electronic laboratory notebook; ELN; IDS; information technology; instrument data systems; laboratory informatics; laboratory information management systems/laboratory information systems; LIMS/LIS; scientific data management systems; SDMS

APPENDIX

(Nonmandatory Information)

X1. LABORATORY INFORMATICS FUNCTIONAL REQUIREMENTS

X1.1 This functional requirements checklist is divided into two parts, a general checklist covering functionality common to the various information systems discussed throughout this guide and a second section with requirements recommended as part of this guide.

X1.2 The laboratory informatics functional requirements checklist is an example of typical requirements that can be used to guide the purchase, upgrade, or development of a laboratory informatics system. While comprehensive in scope, it is important to note that this checklist is not meant to be exhaustive.

X1.3 *Use of the Laboratory Informatics Functions/Requirements*:

X1.3.1 The checklist is set up as a spreadsheet with ten columns, as described in the following:

X1.3.1.1 *Left-most Columns*—Separate columns exist for the major categories of laboratory informatics systems. Laboratory informatics functions can be satisfied by one or more of

the major categories. Users of the checklist can include notations here to indicate whether the requirement is important to the proposed implementation. Recommended symbols to use here are **S** for "Suggested" and **R** for "Required."

(1) SDMS – Scientific Data Management Systems

(2) ELN – Electronic Laboratory Notebook

(3) IDS – Instrument Data Systems (that is, Chromatographic Data Systems)

(4) LIMS/LIS – Laboratory Information Management Systems / Laboratory Information System

(5) OTHER – Users can let this refer to any other systems not otherwise listed

X1.3.1.2 *#*—The requirement number (with reference to the Laboratory Informatics Functions Map (Fig. 3)) numbering scheme.

X1.3.1.3 *Laboratory Informatics Functions/Requirements*—The individual requirement.

X1.3.1.4 *C—Criticality.* Users can specify the overall importance of the requirement. Two examples for scoring criticality are as follows:

(1) Simple: On a scale of one to ten.

(2) Complex:

*(a) Out-of-the-box/user-configurable:***5.** The functionality is available without modification to the application or through configuration settings available to the end user.

*(b) Administrative configuration:***4.** The functionality is available through configuration settings or tools intended for use by trained application experts.

*(c) Minor administrative customization or dependence on third-party product included:***3.** Functionality available through a third-party product included or delivered with the system and intended to be performed by system experts.

*(d) Major administrative customization or dependence on third party product not included:***2.** Functionality available through a third-party product not included or via advanced programming by client.

*(e) Partially met requirement or supplier-supported customization required:***1.**

*(f) Not available or supplier customization is not supported:***0.**

X1.3.1.5 *S—Scope.* Users can specify whether the requirement should be considered in out of scope.

X1.3.1.6 *P—Phase.* For projects that are to be implemented in phases, this column can be used to denote the implementation phase.

X1.3.2 *Guidance on Use of the Laboratory Informatics Functional Requirements:*

X1.3.2.1 Laboratories can complete the checklist as part of the requirements definition process.

X1.3.2.2 Laboratories can submit the Laboratory Informatics Functions Requirements checklist to prospective suppliers / vendors (with or without input from their own requirements process) as part of the vendor selection process where each vendor self-scores.

X1.3.2.3 Laboratory can use the checklist as part of a formal scoring process during a vendor selection/demo evaluation process.

X1.3.2.4 Weighting/criticality can be visible or hidden form prospective vendors.

X1.3.2.5 Where multiple vendor solutions and or third-party tools are used to deliver the laboratory informatics solution to the laboratory, each function should be tied to the vendor solution or third-party tool that is delivering the function.

X1.3.2.6 Each laboratory needs to consider unique requirements to their specific industry or type of laboratory.

NOTE X1.1—**Note regarding criticality scoring**—It is important to identify clearly functionality that has been customized solely for the purposes of a vendor demonstration. This functionality will likely not exist in the core product and should not be considered a **5** on the complex scale.

X1.3.3 The requirements section headings (Table X1.1) map to Laboratory Informatics Functions Map where applicable. See Fig. 3 for quick reference.

TABLE X1.1 Requirements Checklist

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
Sample Registration (Section C-1)									
					C-1-1	The system should allow for the registration of samples prior to or after physical sample collection.			
					C-1-2	The system should allow for the generation of user definable sample labels including the use of bar codes.			
					C-1-3	The system should allow for automated sample registration via different triggering mechanisms including calendars, web requests, and system-to-system methods.			
					C-1-4	The system sample registration functionality should allow for inclusion of metadata (for example, lot, biographical and client information.			
					C-1-5	The system sample registration functionality shall allow for the inclusion of the requested tests, the ability to modify pre-defined tests, and add/remove tests.			
					C-1-6	The system sample registration functionality should include safety information regarding the submitted material.			
					C-1-7	The system sample registration functionality should include the ability of using predefined templates, and the ability to create ad-hoc samples, single samples, and/or multiple samples.			
					C-1-8	The system shall have the ability to define Sample collection details such as container types and sizes, preservation, safety hazards.			
					C-1-9	The system should provide for additional free text or listed descriptive information about a sample to be captured.			
					C-1-10	The system should allow for creation of user definable sample registration preferences/methods and/or input screens.			
Core Laboratory Workflow and Data Management (Sections C-1, C-2, C-3, C-4, C-5)									
					C-1-11	The system sample receipt functionality should include the ability to track sample delivery information (location, time stamp, resource) for a pre-logged sample.			
					C-1-12	The system shall allow for the creation of multiple standard and reagents in one action.			
					C-1-13	The system shall record static instrument information including instrument ID, description, location, calibration interval, maintenance interval and Instrument verification interval.			
					C-1-14	The system shall assign a unique identifier to each sample using an incrementing integer or user-defined naming format.			
					C-1-15	The system shall provide facilities to acknowledge the physical receipt of sample material and the time of receipt in the laboratory (known as receipt or receiving).			
					C-1-16	The system shall provide a mechanism to compare received samples against customer or project sampling requirements to identify variances.			
					C-1-17	The system should allow for documentation of undesired or unexpected characteristics of submitted samples.			
					C-1-18	The system should allow for recording of sample preparation activities.			
					C-1-19	The system shall allow for the recording of every sample's distribution to personnel and location at all times while the sample is in the laboratory's possession. (Aliquoting and chain of custody.)			
					C-2-1	The system should have the ability to manage inventories for reference samples, standards, reagents, and standards.			
					C-2-2	The system shall be able to manage the creation and use of purchased or prepared standards and reagents.			
					C-2-3	The system shall report reorder point quantities for standards and reagents when inventory quantities reach a configurable threshold.			
					C-2-4	The system shall have the ability to automatically send a notification based on reorder point quantity.			
					C-2-5	System shall be able to assign and select by material grade information for a standard/reagent.			
					C-2-6	System shall allow identification of standards/reagents as controlled substances.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
					C-2-7	The system shall have the ability to store data required to track and manage controlled substances at the sample and test level.			
					C-2-8	System shall be able to calculate the Expiration and Use Expiration (the expiration date assigned after the standard or reagent container is received or opened for first use) date based on a pre-defined interval.			
					C-2-9	The system shall record chain of custody for standards and reagents.			
					C-2-10	The system shall allow a user to record the storage location for any standard or reagent.			
					C-2-11	The system shall allow for the re-standardization (assigning a new standard value to a standard that had been previously standardized) of existing standard and reagents.			
					C-2-12	The system shall require the date to be recorded when a standard and reagent is first opened.			
					C-2-13	System shall be able to automatically deactivate expired standards/reagents.			
					C-2-14	System shall permit only active standards and reagents to be available for use.			
					C-2-15	System shall allow manual deactivation of standards/ reagents.			
					C-2-16	The system should have the ability to track time-based samples for shelf-life and stability testing, including orientation, package configurations, and so forth.			
					C-2-17	The system will support the selection of multiple instruments used for an analysis.			
					C-2-18	The system shall provide for a mechanism to group logically associated samples together.			
					C-2-19	The system should provide a facility for identifying a physical sample in the system (barcoded label for example).			
					C-2-20	The system should allow work to be scheduled and allocated against available resources (people and equipment).			
					C-2-21	The system should allow work to be scheduled and allocated against available personnel.			
					C-2-22	The system should provide the ability to manually track the inventory amounts of samples.			
					C-3-1	The system shall be able to assign tests and specifications for standards and reagents.			
					C-3-2	The system shall allow a user to record standard and reagent preparation information.			
					C-3-3	The system shall be able to set the retest date for a standard or reagent based upon on a retest interval.			
					C-3-4	System shall prevent the recording of usage of standards and reagents that are under investigation.			
					C-3-5	The system shall prevent the recording of usage of expired standards and reagents.			
					C-3-6	System shall prevent the use of a media that will expire during testing.			
					C-3-7	The system shall exclude disposed standards and reagents from the inactive standards and reagents.			
					C-3-8	The system will have the ability apply limits (physical, control, specifications) to an instrument sample.			
					C-3-9	The system shall provide an option to create a sample and test to capture data from a calibration, preventative maintenance, or service event.			
					C-3-10	The system should allow for assignment of tests to specific analysts.			
					C-3-11	The system should allow for definition of analyst certification by test.			
					C-3-12	The system should allow for result entry to be done for all tests on a single sample and also for multiple samples for a single test.			
					C-3-13	The system should allow for a user definable result entry method, such as upload from a spreadsheet.			
					C-3-14	The system should allow for a third party laboratory or other entity to enter results into the system.			
					C-3-15	The system should allow for tracking and result entry for outsourced samples. (Aliquoting and chain of custody.)			
					C-3-16	The system should allow for a retest/reprocess loop for tests.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
					C-3-17	The system shall capture results/determinations that are the output of the analysis process in a variety of formats (numeric, text, date/time, pick list, attachments).			
					C-3-18	The system shall include ability to enter operators such as <, >, +, - with numeric data.			
					C-3-19	The system shall capture the date/time the results/ determinations are entered/uploaded into the system.			
					C-3-21	The system should provide a mechanisms for resampling and retesting based on retest date, retest due to out of specification conditions, and so forth.			
					C-3-22	The system should provide utilities to allow for calculations to be performed with result data, inter and intra test, inter and intra sample including the use of advanced math functions.			
					C-3-23	The system shall allow for multiple concurrent user sessions.			
					C-3-24	The system should allow the user to interact with the system for a configurable period of time before being prompted again for authentication credentials.			
					C-4-1	The system shall have the ability to assign a review status to the Standard/Reagent properties and require additional review if properties are changed (expiry, vendor lot number, and so forth).			
					C-4-2	The system shall be able to assign specification limits for instrument tests.			
					C-4-3	The system shall be able to specify instrument accuracy limits or tolerances and indicate to the user when the values are exceeded.			
					C-4-4	The system shall auto-authorize verification check tests and samples if they are within specification limits for interfaced instruments.			
					C-4-5	The system shall provide full audit trail for modified results.			
					C-4-6	The system should provide one or more levels of review and interpretation of results.			
					C-4-7	The system should provide for configurable review and approval of multiple tests at higher levels such as sample, batch, project, experiment levels.			
					C-4-8	The system should allow for the entry configuration of warning/action and material specification limits that can be compared against entered results/determinations to determine whether the results meet specifications or other limit to determine whether the results meet specifications.			
					C-4-9	The system should allow for the entry of electronic signatures for both entered results and documented approvals. This should be configurable based on transaction.			
					C-4-10	The system should flag out-of-range results for further evaluation.			
					C-4-11	The system should allow for the entry of warning and material specification limits that can be compared against entered results/determinations to determine whether the results meet specifications.			
					C-4-12	The system should provide a full configurable audit trail for all changes made to records in the system including personnel identities and time/date of activity.			
					C-5-1	The system should record the final disposition of samples.			
Reporting (Section C-6)									
					C-6-1	The system shall have the ability to store multiple files (such as a PDF of the vendor Certificate of Analysis) in electronic format and associate it with a standard or reagent.			
					C-6-2	The system shall provide time interval tracking facilities for samples so that overdue conditions can be identified or avoided.			
					C-6-3	The system should provide a listing of all tests that shall be performed, the amount of material required, and to which location the samples are to be sent.			
					C-6-4	The system should provide a data report to substantiate the status of the verified results (for example, a Certificate of Analysis).			
					C-6-5	The system shall provide the ability to produce reports.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
					C-6-6	The system should provide a warning to users for entry of out of spec test results (audible, color, icon, screen message).			
					C-6-7	The system should provide for an interface to a third-party reporting tool.			
					C-6-8	The system should provide for the ability for reports to be developed, including but not limited to invoices, project summaries, sampling route lists, sample registration reports, group and analyst work and backlog lists, data reports, business reports, Certificates of Analysis, laboratory performance reports, instrument reports, personnel reports, graphical reports, statistical analysis reports, regulatory reports, audit trail reports, incident reports, chain of custody reports, quality assurance reports, inventory management.			
Document Management (Section D-1)									
					D-1	The system should be well documented with comprehensive manuals for all phases of operation including administration, operation, and troubleshooting.			
Instrument and Equipment Management (Section E-3)									
					E-3-1	The system should have the ability to track laboratory equipment/instrument usage.			
					E-3-2	The system shall have the ability to 'reserve' / plan usage of instrument for work planning purposes.			
					E-3-3	The system shall have the capability to take an instrument off-line/unavailable based upon a configurable scheduler.			
					E-3-4	The system should be capable of recording instrument touch time for use in capacity planning/scheduling.			
					E-3-5	The system shall support user configuration and recording of multiple instrument events for the same instrument (different event types, different frequencies for same event type, and so forth).			
					E-3-6	The system will have the capability to group instruments together (that is, balances group to include like type balances, or to group by instrument type and by laboratory).			
					E-3-7	The system shall have the ability to set tolerance limit and/or calibration period by intervals of days, weeks, months or years.			
					E-3-8	The system shall have the ability to email a notification when an instrument reaches its tolerance date limit or calibration due date.			
					E-3-9	The system shall indicate out of calibration instruments, instruments beyond their preventative maintenance due date and instruments under investigation and prevent their selection for use.			
					E-3-10	The system shall allow an instrument to be manually placed online or offline.			
					E-3-11	The system shall be able to record the multiple occurrences of next calibration date, next preventative maintenance date, and service date.			
					E-3-12	The system shall be able to calculate Instrument event dates based upon a pre-defined interval.			
					E-3-13	Each instrument or instrument part registered within the system shall be uniquely identified.			
					E-3-14	The system shall have the capability to automatically take a parent instrument offline when a child instrument / or part goes offline, for example, a detector or pump will represent the child instruments of a HPLC.			
					E-3-15	The system should provide a mechanism of defining instruments including calibration and maintenance schedules.			
System Infrastructure, Integration, and Interfaces (Sections E-6, E-8, E-10, E-13)									
					E-6-1	The system shall have the capability to trigger an instrument event based upon the number of uses of that instrument.			
					E-6-2	The system shall be able to automatically take an instrument offline when calibration or maintenance dates expire.			
					E-6-3	The system should provide auto sampler and robotic system controls.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
					E-6-4	The system should capture the personnel or instrument information relating to the results/ determinations entered into the system.			
					E-6-5	In cases where instruments interface with the system, the system should accept the results uploaded from the instrument.			
					E-6-6	In cases where instruments interface with the system, the system should transfer the sequence of unknown samples and control standards to the instrument.			
					E-6-7	The system should support integration with simple laboratory instruments via RS 232 connection.			
					E-6-8	The system should support bi-directional interface with complex laboratory instrumentation software.			
					E-6-10	The system should provide utilities to allow for calculations to be performed with result data, inter and intra test, inter and intra sample including the use of advanced math functions.			
					E-6-11	The system should have the ability manage the volume of data produced by the laboratory.			
					E-6-12	Interactions with the system should exhibit low network latency.			
					E-8-1	The system should provide the ability to track the inventory amounts of samples.			
					E-10-1	The system should provide a means to configure automatic generation of trending and control charts.			
					E-10-2	Perform calculations on raw results to obtain final results, perform rounding to predetermined digits, store associated QC results for calibrations, standard checks, blank corrections, and so forth.			
					E-13-1	The system should provide a means to communicate status changes for dynamic entities (samples, lots, instruments, etc.) to and from external systems.			
					E-13-2	The system should provide a means to communicate status changes to external systems.			
					E-13-3	The system should provide a mechanism to archive data, including data and metadata.			
					E-13-4	The system should provide a mechanism to restore archived data.			
					E-13-5	The system should be based on a reliable, effective, and supported data storage system.			
					E-13-6	The system should provide for an interface to a third-party reporting tool.			
					E-13-7	The system should conform to the data storage platforms and standards currently in place in your enterprise.			
					E-13-8	The system's data storage mechanism should support the ability to modify the data structures as needed.			
					E-13-9	The system's data storage tools should allow for multiple environments (that is, development and production) and the ability to move records from one environment to another.			
					E-13-10	The system's data storage tool shall contain the ability to fine tune performance and security of data.			
					E-13-11	The system's data storage tools should support industry best practices for backup and recovery.			
					E-13-12	The system's architecture should be clearly separated into logical modules with standard interfaces between the modules.			
					E-13-13	The system should use the system and hardware platform as efficiently as possible to allow for concurrent usage and high peak usage.			
					E-13-14	The system should present a well-documented application programming interface (API) for interfacing with the application's underlying functionality at a granular level.			
					E-13-15	The system should provide a means to integrate and exchange data based on common methods.			
					E-13-16	The system's data storage tools shall be replicable to ensure recoverability in the event of hardware failure.			
					E-13-17	The system should support interfacing with the company's enterprise resource planning (ERP) wide systems.			
					E-13-18	The system should be able to interface with enterprise middleware.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
Lean Laboratory/Continuous Improvement (Section E-15)									
					E-15-1	The system should allow for the automation of the controlled release of work into the laboratory based on the workload leveling strategy.			
					E-15-2	The system should allow for visual and quick assessment of the work flow processes at strategic points.			
					E-15-3	The system should provide tools that map actual workflow identifying potential failure points.			
System Configuration (Section S-1)									
					S-1-1	The system will allow for the entry and management of user configurable lookup/master data.			
					S-1-2	The system will allow for the configuration of the appropriate laboratory workflows.			
					S-1-3	The system will allow for the assignment of status values to track progress of samples or other entities in the laboratory workflow.			
					S-1-4	The system should allow for revision control of lookup/master data on a user defined basis.			
					S-1-5	The system should allow for importation of lookup/master data.			
					S-1-6	The system shall include ability to define rounding rules for numeric data.			
					S-1-7	The system should allow for the creation of calculated limits based on test results and relevant metadata.			
					S-1-8	The system should provide a warning to users for entry of out of spec test results (audible, color, icon, screen message, email notification).			
					S-1-9	The system shall provide a means to update static and dynamic data (for example, samples information, tests results, specifications, and so forth).			
					S-1-10	The system should provide a means for user defined actions to trigger based on workflow events or status changes.			
					S-1-11	The system should secure data and operations from unintended exposure/use by unapproved personnel.			
					S-1-12	The system should provide administrative interfaces that allow approved users to configure the system without programming or direct manipulation of the data storage system.			
					S-1-13	The system should provide a programming tool to customize the applications or build calculations within the application.			
					S-1-14	The system should present a multiple user interfaces that reflect the specific geographic needs of local users including elements of language, character sets, and time zones.			
					S-1-15	In FDA regulated environments the system should support CFR 21 Part 11 rules governing electronic signatures.			
					S-1-16	The system should provide a security interface that prevents unauthorized access to data and functions that can be conveniently administered for all modules of the system.			
					S-1-17	The system should provide for a unified authentication scheme whereby a user can sign on once and access all permitted functions and data.			
					S-1-18	The system shall meet enterprise password policy guidelines.			
					S-1-19	The system should comply with applicable regulatory standards and company standards for electronic signatures.			
					S-1-20	The system should support the ability to assign individual users to system groups and or roles.			
					S-1-21	The system should provide tools for static data migration into the system.			
Validate/Commission Systems (Section S-2)									
					S-2-1	The vendor should have established software development standards, formal change control, software revision control. Vendor staff quality and skills should be documented.			
					S-2-2	The vendor should provide access to source code.			
					S-2-3	The system should provide functionality to summarize and evaluate performance markers and processes of the enterprise.			

TABLE X1.1 *Continued*

SDMS	ELN	IDS	LIMS/LIS	OTHER	# (Fig. 3)	Laboratory Informatics Functions / Requirements	C	S	P
System Administration (Section S-3)									
					S-3-1	The system should allow for batch modification of personnel data including groups and role assignments.			
					S-3-2	The system should support storage of a wide variety of data formats utilized by the organization.			
					S-3-3	The system should support the ability to assign individual users to system groups and/or roles.			
					S-3-4	The system should allow for batch modification of personnel data including groups and role assignments.			
					S-3-5	The vendor should provide information on the number of systems installed, number of years in the business with specific system, certifications for federal, local, or international regulatory standards, cost of system including hardware, software, network, training, implementation, and support.			
					S-3-6	The vendor should provide references of established customers.			
					S-3-7	The vendor should provide maintenance agreements and support services.			
					S-3-8	The vendor shall provide help desk support, training support, installation support, and high quality documentation.			
					S-3-9	The system should integrate with an organization's enterprise personnel security directory and/or physical security systems.			
					S-3-10	The vendor should provide upgrades and documentation for the upgrade. Site system administrators should be able to perform the upgrade.			
					S-3-11	The upgrade shall provide a means to migrate data to a new release.			
					S-3-12	The system should allow for fast retrieval of stored items.			
					S-3-13	The system should support interaction with mobile technologies like smartphones, tablet PCs for timely notification of imminent or actual issues.			
					S-3-14	The upgrade shall include capability to install in parallel for testing.			
					S-3-15	The upgrade shall provide a means to migrate data to new release.			

BIBLIOGRAPHY

The references shown here provide additional sources of information related to laboratory informatics. The landscape of laboratory informatics is changing rapidly. This list of resources is intended to inform the reader of the many organizations involved in this area.

ASTM Standards:[2]

(1) E1947 Specification for Analytical Data Interchange Protocol for Chromatographic Data

(2) E1948 Guide for Analytical Data Interchange Protocol for Chromatographic Data

(3) E2077 Specification for Analytical Data Interchange Protocol for Mass Spectrometric Data

(4) E2078 Guide for Analytical Data Interchange Protocol for Mass Spectrometric Data

ANSI Standard:[20]

(5) ANSI HL7 Arden Syntax for Medical Logic Systems

EPA Data Standard:[3]

(6) 40 CFR 792 Code of Regulations, 54 FR 34043, August 17, 1989

[20] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

Data Exchange Standards:

(7) AnIML (Analytical Information Markup Language) an emerging data standard for laboratory instruments covering multiple analytical techniques. The E13.15 subcommittee is responsible for the development of this standard.[21]

(8) NetCDF (Network Common Data Form) an interface for array-oriented data access and a library that provides an implementation of the interface. The netCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. Unidata Program Center at the University Corporation for Atmospheric Research (UCAR).[22]

(9) EPA Environmental Response Laboratory Network[23] (ERLN) "Requirements for Environmental Response Laboratory Network Data Submissions" a granular-level environmental electronic data deliverable (EDD) with a standardized, defined list of data elements and their associated data structures and components. This EDD is agnostic with regard to method, matrix, or governmental program and is used by public and private laboratories to provide emergency response laboratory data. The companion "WEBEDR" is a web service that provides data exchange and automated data review.

(10) SCRIBE[24] Scribe is a software tool developed by the USEPA's Environmental Response Team (ERT) to assist in the process of managing environmental data. Scribe captures sampling, observational, and monitoring field data.

(11) Exchange Network[25] The Environmental Information Exchange Network provides information on several data exchange formats including eDWR, SDWIS, AQDE, AQS-Air, ICIS-NPDES-Water, NetDMR, OWIR, ODPX, WQDE, WQX, HERE, SRS Staged Electronic Data Deliverable (SEDD) EPA—eXtensible Markup Language (XML)—joint standard developed by US EPA Office of Superfund Remediation and Technology Innovation (OSRTI) Analytical Services Branch (ASB) and US Army Corps of Engineers (US ACE)[26]

(12) ISO/IEC 12207 Subcommittee for Electronic Data Standards (SEDS), reference spectroscopic databases sponsored by the International Union of Pure and Applied Chemistry (IUPAC) and standards related to the Joint Committee on Atomic and Molecular Physical Data (JCAMP) and JCAMP-DX (XML in the chemistry area) ISO Standards

(13) SiLA[27] The Standardization in Lab Automation consortium develops standards for the integration of laboratory instrumentation and the exchange of data between laboratory systems.

Clinical and Health Data Standards and Networks:

(14) LRN[28] The National Centers for Disease Control and Prevention (CDC) manages the Laboratory Response Network (LRN). This includes the CDC LRN-Biological (LRN-B) and CDC LRN-Chemical (LRN-C).

(15) BioWatch[29] An early warning environmental monitoring system used to detect trace amounts of biological materials in the air managed by the U.S. DHS with partners EPA and the CDC. BioWatch utilizes the LRN Result Messenger, with similar data delivery as used with the LRN-B and LRN-C.

(16) FERN[30] The Food Emergency Response Network (FERN) is managed by USDA Food Safety and Inspection Service and FDA. FERN uses the Electronic Laboratory Exchange Network (eLEXNET), which allows multiple government agencies engaged in food safety activities to compare, communicate, and coordinate findings of laboratory analyses.

(17) NAHLN[31] The National Animal Health Laboratory Network's (NAHLN) purpose is to enhance the nation's early detection of, response to, and recovery from animal health emergencies, including bioterrorist incidents, newly emerging diseases, and foreign animal disease agents that threaten the nation's food supply and public health.

(18) NPDN[32] The National Plant Diagnostic Network (NPDN) is managed by USDA NIFA and APHIS.

(19) DLN[33] The DoD Laboratory Network's (DLN's) is a coordinated and operational system of Department of Defense.

Environmental/Chemical Data Exchanges:

(20) APHL EDD[34] The Association of Public Health Laboratories system for Environmental Data Delivery based on the EPA ERLN. This EDD is agnostic to methods, matrix, and program.

(21) STELLAR[35] provided to State and local Childhood Lead Poisoning Prevention Programs (CLPPPs) that documents medical and environmental activities in lead poisoning cases).

(22) NAACCR[36] North American Association for Central Cancer Registries which provides central registry structural requirements, process standards, and outcome measures for access to source data and completeness of reporting, data quality, data analysis and reporting, and data management.

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[21] Schaefer, B. A., Poetz, D., and Kramer, G. W., "Documenting Laboratory Workflows Using the Analytical Information Markup Language," *Journal of the Association for Laboratory Automation*, Vol 9, No. 6, 2004, pp. 375–381.

[22] Available from University Corporation for Atmospheric Research (UCAR), P.O. Box 3000 Boulder, CO 80307-3000, http://www.unidata.ucar.edu/software/netcdf.

[23] For additional information, visit http://www.epa.gov/oemerln1/.

[24] Available from USEPA Environmental Response Team Center (ERT), ERT Software Support Building 205, 2890 Woodbridge Avenue Edison, NJ 08837, http://www.ertsupport.org/scribe_home.htm.

[25] For additional information, visit http://www.exchangenetwork.net/data-exchange/.

[26] Available from U.S. Environmental Protection Agency (USEPA), Office of the Science Advisor (8105R), 1200 Pennsylvania Avenue, NW, Washington, DC 20460, http://www.epa.gov/superfund/programs/clp/sedd.htm.

[27] Additional information available from Association Consortium Standardization in Lab Automation (SiLA), Laubisrütistrasse 44, CH-8712 Stäfa, Switzerland, http://www.sila-standard.org.

[28] For additional information, visit http://emergency.cdc.gov/lrn/

[29] For additional information, visit http://www.oig.dhs.gov/assets/Mgmt/OIG_07-22_Jan07.pdf.

[30] For additional information, visit http://www.fernlab.org/.

[31] For additional information, visit http://www.aphis.usda.gov/animal_health/nahln/.

[32] For additional information, visit http://www.npdn.org/.

[33] For additional information, visit http://www.dtic.mil/whs/directives/corres/pdf/644003p.pdf.

[34] Additional information available from Association of Public Health Laboratories, 8515 Georgia Avenue, Suite 700, Silver Spring, MD 20910, http://www.aphl.org/AboutAPHL/publications/Documents/EH_2012May_Requirements-for-Environmental-Electronic-Data-Delivery-Submissions-Report.pdf.

[35] For additional information, visit http://www.cdc.gov/nceh/lead/data/stellar.htm.

[36] Additional information available from North American Association of Central Cancer Registries, Inc. (NAACCR), 2121 West White Oaks Drive, Suite B, Springfield, IL 62704-7412, http://www.naaccr.org.

(23) PHDSC[37] The Public Health Data Standards Consortium is an organization of federal, state, and local health agencies; professional associations, academia; public and private sector organizations; international members; and individuals. Its goal is to empower the healthcare and public health communities with health information technology standards to improve individual and community health.

FDA Regulations:[4]

(24) FDA 21 CFR 58 Good Laboratory Practice for Non-Clinical Studies, 43 Federal Register 60013, Dec. 22, 1978

(25) FDA 21 CFR 211 Current Good Manufacturing Practice For Finished Pharmaceutical Products, 43 Federal Register 45077, September 29, 1978 and 73 Federal Register 51932, September 8, 2008

(26) FDA Compliance Program Guide 7346.832 Pre-Approval Inspections published May 2010, effective May 2012

(27) FDA 21 CFR 820 Quality System Regulation, 61 Federal Register 52654, October 7, 1996

GAMP:[5]

(28) GAMP Good Practice Guide Validation of Laboratory Computerized Systems, Second Edition, ISPE, 2012

(29) GAMP Good Practice Guide A Risk-Based Approach to Operation of GxP Computerized Systems—A Companion Volume to GAMP® 5, 2010

(30) GAMP Good Practice Guide Electronic Data Archiving, 2007

(31) GAMP Good Practice Guide IT Infrastructure Control and Compliance, ISPE, 2005

ICH Standards:[6]

(32) ICH Q10 Pharmaceutical Quality Systems

(33) ICH Quality Guideline Q8 Pharmaceutical Development

[37] Additional information available from Public Health Data Standards Consortium (PHDSC), 111 South Calvert Street, Suite 2700, Baltimore MD 21202, http://www.phdsc.org/standards/health-information/d_standards.asp.

For an in-depth review of lean concepts, refer to the following sources:

(34) Liker, Jeffrey K., *The Toyota Way*, McGraw-Hill, New York, 2004.

(35) Ohno, Taiichi, *Toyota Production System*, Productivity Press, New York, 1988.

(36) Womack, James P. and Jones, Daniel T., *Lean Thinking*, Free Press, New York, 2003.