July 2024
Report No. 24-052

Laboratory Information Materials Management System (LIMMS) Development Planning

Principal Investigator (s)
Russell Tessier

University of Massachusetts—Amherst

Research and Technology Transfer Section
MassDOT Office of Transportation Planning

U.S. Department of Transportation
Federal Highway Administration

[This blank, unnumbered page will be the back of your front cover]

Technical Report Document Page

1. Report No. 24-052	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Laboratory Information Materials Management System (LIMMS) Development Planning		5. Report Date July 31, 2024 6. Performing Organization Code
7. Author(s) Russell Tessier		8. Performing Organization Report No. 24-052
9. Performing Organization Name and Address Knowles Engineering Building, University of Massachusetts, Amherst, MA 01003		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Massachusetts Department of Transportation Office of Transportation Planning Ten Park Plaza, Suite 4150, Boston, MA 02116		13. Type of Report and Period Covered Final Report - July 2024 (March 2023 - July 2024) 14. Sponsoring Agency Code n/a
15. Supplementary Notes Project Champion - Alana Geary, MassDOT		

16. Abstract

The purpose of this project was to conduct a gap analysis that examined the needs of LIMMS users from system design and functionality to security. The analysis took into consideration the multiple platforms used by MassDOT currently for material and contract management. During the project, feedback was obtained from MassDOT users via private meetings and workshops to understand the scope of LIMMS usage. Given the increasing threat of software attacks, security was a particular focus of information gathering.

A gap analysis report was created based on feedback from MassDOT users, a literature review, information gathered from other DOTs, and an evaluation of alternative material management products. Interviews with employees at other DOTs examined common use cases for alternative products. These products were evaluated via vendor interviews and software demonstrations. The gap analysis report findings resulted in a detailed and accurate scope of work for a sustainable and efficient LIMMS system.

17. Key Word Gap analysis, LIMMS, materials, samples, testing, mobile interface, data storage	18. Distribution Statement unrestricted		
19. Security Classif. (of this report) unclassified	20. Security Classif. (of this page) unclassified	21. No. of Pages 72	22. Price n/a

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page left blank intentionally.

Laboratory Information Materials Management System (LIMMS) Development Planning

Final Report

Prepared By:

Russell Tessier
Principal Investigator

Knowles Engineering Building
University of Massachusetts
Amherst, MA 01003

Prepared For:

Massachusetts Department of
Transportation Office of
Transportation Planning
Ten Park Plaza,
Suite 4150 Boston,
MA 02116

July 2024

This page left blank intentionally.

Acknowledgments

Prepared in cooperation with the Massachusetts Department of Transportation, Office of Transportation Planning, and the United States Department of Transportation, Federal Highway Administration.

The Project Team would like to acknowledge the efforts of the project co-investigators, Chengbo Ai, Jeremy Gummeson, and Egemen Okte and students, Zhehang Zhang, Matt Corcoran, and Xiaoxuan Liang.

Disclaimer

This page left blank intentionally.

Executive Summary

This study of Laboratory Information Materials Management System (LIMMS) Development Planning was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

A LIMMS is a secure materials data collection system that is often used by department of transportation (DOT) personnel. A LIMMS includes a range of software tools that can be used to track the acquisition and testing of materials for transportation systems statewide. To assist MassDOT in obtaining a next generation LIMMS, research is needed to better understand the spectrum of alternative commercial and open-source material management systems, their functionality, and their ability to be customized and extended. In addition to addressing functionality, system security must be considered. This project has provided an opportunity to investigate software that can meet or exceed MassDOT's design and security requirements.

A gap analysis was performed that examined the needs of LIMMS users from system design and functionality to security. The analysis took into consideration the multiple platforms used by MassDOT currently for material and contract management (including material inspection, material testing, and material documentation systems). During the project, feedback was obtained from MassDOT users via private meetings and workshops to understand the scope of LIMMS usage. Given the increasing threat of software attacks, security was a particular focus of information gathering.

A gap analysis report, whose information is included in this document, was created based on feedback from MassDOT users, a literature review, information gathered from other DOTs, and an evaluation of alternative material management products. Outreach to contacts at other DOTs was performed to document common use cases for alternative products. Six commercial products were evaluated via vendor interviews and software demonstrations. Following these demonstrations, a decision was made by MassDOT to pursue the implementation of an in-house developed LIMMS based on Microsoft products.

To assist in the development of the in-house LIMMS, a three-hour workshop was held in January 2024 that included forty MassDOT employees. The workshop identified features that should be included in a next-generation LIMMS. Following the workshop, the design of several electronic test forms was performed. Variants of these forms may be included in the new MassDOT LIMMS.

This page left blank intentionally.

Table of Contents

List of Tables

List of Figures

This page left blank intentionally.

List of Acronyms

Acronym	Expansion
ADA	Americans with Disabilities Act
AWS	Amazon Web Service
CMS	Contract Management System
COTS	Commercial off the shelf
DME	District materials engineer
DOT	Department of transportation
DQE	District quality engineer
FHWA	Federal Highway Administration
GUI	Graphical user interface
IT	Information technology
LIMS	Laboratory information management systems
LIMMS	Laboratory information materials management system
MassDOT	Massachusetts Department of Transportation
MMS	Materials management system
MS	Microsoft
NCR	Non-compliance report
RFI	Request for information
RFID	Radio frequency identification
SAM	Site Application Module
TAMP	Transportation asset management plan
TISH	Transportation Information Superhighway
TRF	Test report form
UMass	University of Massachusetts

This page left blank intentionally.

1.0 Introduction

This study of Laboratory Information Materials Management System (LIMMS) Development Planning was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

1.1 Problem Statement

A Laboratory Information Materials Management System (LIMMS) is a secure materials data collection system that is in use by numerous departments of transportation (DOTs) including MassDOT. LIMMS includes a range of software tools that can be used to track the acquisition and testing of materials for transportation systems statewide. The LIMMS used by MassDOT until March 2023 is limited in its flexibility, does not straightforwardly support functionality extensions, and may not adhere to contemporary software security standards. Research can provide a better understanding of the spectrum of alternative commercial and open-source material management systems, their functionality, and their ability to be customized and extended to meet the current and future needs of MassDOT. In addition to addressing functionality, system security must be considered. This project provides an opportunity to investigate software solutions that can meet or exceed MassDOT's design and security requirements. Components of the project include a literature review, interviews with LIMMS vendors and other DOTs, and the design of sample test forms using Microsoft Power Apps.

1.2 Research Objectives

The purpose of this project is to conduct a gap analysis that will examine the needs of LIMMS users from system design and functionality to security. The analysis takes into consideration the multiple platforms used by MassDOT currently for material and contract management (including material inspection, material testing, and material documentation systems). During the project, feedback was obtained from MassDOT users via private meetings and workshops to understand the scope of LIMMS usage. Given the increasing threat of software attacks, security was a particular focus of information gathering. This information was used to help MassDOT design a next generation material management product.

A gap analysis report was created based on feedback from MassDOT users, a literature review, information gathered from other DOTs, and an evaluation of alternative material management products. Outreach to contacts at other DOTs was performed to document common use cases for alternative products. Six commercial products were evaluated via

vendor interviews and software demonstrations. The project culminated with a three-hour workshop in January 2024 to discuss LIMMS options with MassDOT staff. Initial mockups of sample and test entry forms were prepared using Microsoft Power Apps.

Specific objectives and their completion status:

Objective 1. Gap analysis of LIMMS with MassDOT staff. The research team conducted a gap analysis through a series of meetings and workshops with current LIMMS users and MassDOT leadership. This task includes a meeting with the MassDOT security team to clarify the role of security in this project and emphasize security needs in a next generation material management product.

Objective 2. Analysis of LIMMS vendors and products used by DOTs in the US for material inspection, testing and documentation. The PIs contacted representatives from multiple DOTs located throughout the country and nine interviews were conducted.

Objective 3. Compilation of the gap analysis report. A gap analysis report based on findings from workshops, an interview with the MassDOT IT security team, and a review of MassDOT platforms was prepared.

Objective 4. Design and implementation of a LIMMS design workshop. MassDOT ultimately decided on the self-implementation of a LIMMS. A workshop with MassDOT personnel was conducted to determine the structure and features of a self-implemented LIMMS.

Objective 5. Design of forms for a LIMMS system. Sample record forms for a LIMMS system were created using Microsoft Power Apps.

1.3 Report Outline

This report includes the following sections. Section 2 describes our research methodology. Activities included holding interviews and workshops, attending demonstrations, and implementing electronic test forms. Section 3 presents the results from our work except for the test form implementation which is discussed in Section 4. We summarize our findings, offer recommendations, and conclude in Section 5.

2.0 Research Methodology

In this section, we review the methodology used to perform a literature review, interview MassDOT employees and employees from other state DOTs, and participate in vendor demonstrations. The methodology used to create electronic test forms using Microsoft Power Apps is also examined.

2.1 Literature Review

Most states use commercial or in-house created LIMMS products. To better understand LIMMS usage, a search of public domain information was performed to identify the LIMMS used in all fifty states. All of the documents used were found via a web search. In total, current LIMMS usage was located for 38 out of 50 states. Details of the literature review are provided in Section 3.1.

2.2 Interviews with MassDOT Staff

Starting in February 2023, the Project Team from the University of Massachusetts Amherst worked with researchers and staff from the Massachusetts Department of Transportation (MassDOT) on defining the parameters of a next generation LIMMS for MassDOT. This work included a series of approximately one-hour interviews with MassDOT stakeholders including the LIMMS Steering Committee, district materials engineers (DME), district quality engineers (DQE), lab technicians, client administrators, and information technology (IT) security personnel. A summary of results from these discussions appears in Section 3.2.

2.3 Interviews with DOTs and LIMMS Vendors

Interviews with nine state DOTs (Connecticut, Illinois, Louisiana, Maine, Michigan, New Hampshire, New York, Rhode Island, and Utah) were conducted to learn of their LIMMS experiences. A series of interviews with six companies that produce and sell LIMMS products was also performed. The DOT and company interviews were conducted by the project team and Massachusetts Department of Transportation (MassDOT) staff. A summary of the interviews appears in Sections 3.3 and 3.4. Product features are summarized in Section 3.5. A survey provided to state DOTs is included in Appendix A.

2.4 LIMMS Design Workshop

Following vendor interviews, MassDOT decided to develop a new LIMMS in-house. On January 24, 2024, a three-hour workshop was held at the MassDOT Research and Materials facility in Hopkinton, MA to identify priorities for MassDOT LIMMS development. Approximately forty MassDOT employees, including district materials engineers, district quality engineers, lab technicians, quality assurance engineers, resident engineers, field inspectors, and MassDOT administrators, and the UMass project team attended. Six discussion stations were set up in the workshop room. LIMMS topics discussed at the stations included RMS360, sampling, testing, documentation, reporting, and interface. Workshop attendees were split into five groups. Each group visited each of the six stations for about 15 minutes each. Groups were encouraged to address the following three questions during each 15-minute session.

- What do you need to see in a LIMMS to do your job?
- What do you want to see when you first log in to the top-level page of your portion of the LIMMS (e.g., sampling, testing, reporting, etc.)
- What LIMMS features could you use right away?

The results of the workshop are summarized in Section 3.6 and LIMMS recommendations based on the workshop appear in Section 3.7.

2.5 Test Form Development with Power Apps

This activity involved the development of a series of test report forms (TRFs) using Microsoft (MS) Power Apps. The goal of this effort is to create electronic forms that have a similar appearance to forms currently in use by MassDOT. The electronic forms will allow for automated data storage in the new LIMMS using a familiar interface. MassDOT provided seven sample TRFs. An example workflow for sample test card entry in Microsoft Power Apps and Dataverse was created. Tables in MS Dataverse cards were populated with data from Excel worksheets provided by MassDOT. These tables hold materials data for hot mix asphalt, concrete, and structural paint. We present preliminary results of form creation in Section 4.0.

3.0 Results

In this chapter, we review the results of the literature search, interviews, demonstrations, and workshops.

3.1 Literature Review

Since 2012, with the introduction of the Moving Ahead for Progress in the 21st Century Act (MAP-21), the Federal Highway Administration (FHWA) has developed guidelines and requirements for state DOTs to manage and monitor their assets in the form of transportation asset management plans (TAMPs) *(1)*. Overall, a state's plan, at the minimum, must include a summary of pavement and bridge asset conditions, asset management objectives and measures, performance gaps, and life-cycle costs. Safety, congestion reduction, system reliability, and environmental sustainability are important TAMP outcomes. The Commonwealth of Massachusetts's TAMP serves the overarching goals of reliability, modernization, and expansion *(2)*. A list of state TAMP documents is provided in Table 3.1.

A key aspect of efficient asset management and TAMP compliance is ensuring the use of suit- able materials and supplies. Laboratory information material management systems, alternatively referred to as material management systems (MMS) or laboratory information management systems (LIMS), play an important role by providing data and information that can be used to make informed decisions about asset management. These software systems assist agencies in evaluating trade-offs in resource allocation and improve the overall asset management process *(52)*. A LIMMS provides a centralized platform to manage materials data, including sample tracking, test result monitoring, and quality control. By using a LIMMS, state DOTs can accurately collect, manage, and share data between departments and districts, improving the accuracy and reliability of transportation asset management. LIMMS generally automate manual tasks associated with data collection and collation following materials testing, such as report generation and communication among various stakeholders *(53)*. An effective LIMMS facilitates materials data access and management for both external and internal users *(54)*. However, due to varying needs and interfaces to supporting software systems, LIMMS usage may vary significantly from state to state.

3.1.1 LIMMS Products and DOT Usage

Commercial LIMMS products are offered by numerous companies, including AASHTOWare *(54)*, Aurigo *(86)*, ExeVision *(87)*, Headlight *(88)*, Thermo Fisher *(89)*, and SynapticSci *(90)*, among others. We will review products from each of these companies in depth in Section 3.4. Most state DOTs have integrated commercial LIMMS in their materials workflows or are in the process of developing their own custom LIMMS.

Table 3.1: State DOT TAMPs

State	Reference	State	Reference
Alabama	*(3)*	Montana	*(4)*
Alaska	*(5)*	Nebraska	*(6)*
Arizona	*(7)*	Nevada	*(8)*
Arkansas	*(9)*	New Hampshire	*(10)*
California	*(11)*	New Jersey	*(12)*
Colorado	*(13)*	New Mexico	*(14)*
Connecticut	*(15)*	New York	*(16)*
Delaware	*(17)*	North Carolina	*(18)*
Florida	*(19)*	North Dakota	*(20)*
Georgia	*(21)*	Ohio	*(22)*
Hawaii	*(23)*	Oklahoma	*(24)*
Idaho	*(25)*	Oregon	*(26)*
Illinois	*(27)*	Pennsylvania	*(28)*
Indiana	*(29)*	Rhode Island	*(30)*
Iowa	*(31)*	South Carolina	*(32)*
Kansas	*(33)*	South Dakota	*(34)*
Kentucky	*(35)*	Tennessee	*(36)*
Louisiana	*(37)*	Texas	*(38)*
Maine	*(39)*	Utah	*(40)*
Maryland	*(41)*	Vermont	*(42)*
Massachusetts	*(2)*	Virginia	*(43)*
Michigan	*(44)*	Washington	*(45)*
Minnesota	*(46)*	West Virginia	*(47)*
Mississippi	*(48)*	Wisconsin	*(49)*
Missouri	*(50)*	Wyoming	*(51)*

Table 3.2 documents the LIMMS used by 38 of 50 state DOTs. LIMMS information for the remaining 12 states could not be located in the public domain. Table 3.3 summarizes product details obtained from the referenced literature for the five companies listed in Table 3.2. Employee counts were obtained or estimated from company LinkedIn profiles. Twenty-four state DOTs use an AASHTOWare product, by far the most popular commercial LIMMS. These DOTs often share AASHTOWare modules with one another, leading to expandability. Products from ExeVision, Headlight, and Aurigo are increasing in popularity and allow for per-DOT customization. SynapticSci is a relatively new LIMMS player. The company is currently working with MaineDOT to develop a flexible LIMMS product. Further product details obtained from Zoom interviews with DOTs and representatives from these five companies will be provided in Section 3.4.

Table 3.2: Summary of DOT LIMMS usage

State	System	Portal	Reference	Year
Alabama	In-house	Login	*(55)*	2024
Alaska	AASHTOWare	Login	*(56)*	2023
Arkansas	AASHTOWare	N/A	*(53)*	2018
Colorado	AASHTOWare	N/A	*(57)*	2023
Connecticut	AASHTOWare	Login	*(58)*	2023
Florida	In-house	N/A	*(59)*	2014
Georgia	AASHTOWare	N/A	*(60)*	2024
Illinois	ExeVision	Login	*(61)*	2024
Iowa	In-house	N/A	*(62)*	2019
Kansas	AASHTOWare	Login	*(63)*	2022
Kentucky	AASHTOWare	N/A	*(64)*	2020
Louisiana	Headlight	Login	*(65)*	2023
Maine	Synaptic Sci	N/A	*(66)*	2023
Maryland	In-house	Login	*(67)*	2022
Massachusetts	In-house			2024
Michigan	AASHTOWare	N/A	*(68)*	2023
Minnesota	AASHTOWare	Login	*(64)*	2020
Mississippi	AASHTOWare	N/A	*(64)*	2020
Missouri	AASHTOWare	N/A	*(69)*	2019
Montana	AASHTOWare	Login	*(70)*	2022
Nebraska	AASHTOWare	N/A	*(71)*	2018
Nevada	AASHTOWare	N/A	*(72)*	2018
New Hampshire	ExeVision	Login	*(61)*	2024
New Jersey	AASHTOWare	N/A	*(73)*	2024
New York	AASHTOWare	N/A	*(74)*	2024
Ohio	AASHTOWare	Login	*(75)*	2024
Oklahoma	AASHTOWare	Login	*(76)*	2024
Oregon	AASHTOWare	N/A	*(77)*	2024
Pennsylvania	In-house	Login	*(78)*	2017
Rhode Island	Headlight	N/A	*(79)*	2023
South Carolina	AASHTOWare	Login	*(80)*	2023
Tennessee	AASHTOWare	Login	*(81)*	2023
Utah	Aurigo	Login	*(82)*	2023
Vermont	ExeVision	N/A	*(83)*	2024
Washington	In-house	N/A	*(53)*	2018
West Virginia	AASHTOWare	N/A	*(84)*	2015
Wisconsin	AASHTOWare	N/A	*(85)*	2023
Wyoming	ExeVision	N/A	*(61)*	2024

Six state LIMMS are listed in Table 3.2 as developed in-house. Alabama has created the Construction and Materials Management System (CAMMS) *(55)*. This platform supports

mobile entry using an IPad, report generation, change orders, and external access by vendors. The software system is web-based. An in-house LIMMS developed by Florida builds on a pre-existing Materials Acceptance and Certification platform *(53)*. Features of the LIMMS include test result entry, multi-layer approval, and linkage with contracts. The software is web-based and built upon Florida's Citrix software infrastructure *(59)*. Iowa's LIMMS is web-based and centered around an Oracle database *(62)*. Maryland's in-house LIMMS *(67)*, LIMS-MMS, supports materials sampling, testing, and reporting *(53)*. The software is dashboard-based and was implemented in modules for lab results entry and review and test assignment. Pennsylvania's eCAMMS LIMMS is web-based and went into production in 2014 *(78)*. Washington State DOT's client-based system, Materials Testing System (MATS), was implemented in 2005 *(53)*. It can be used to certify, approve, and track materials. MassDOT is currently developing an in-house LIMMS based on Microsoft products including SharePoint and Power Apps. This system will likely support mobile data entry using tablets and phones.

Table 3.3: Summary of widely used LIMMS products with company employee count

Company	Suite	Capabilities	Emp. Count	Ref.
AASHTOWare	AASHTOWare Project Construction and Materials - Site Manager	Material approval, qualification check for testers, samplers, and laboratories, access restriction based on user level, mix design database creation and mix approval, materials life-cycle tracking.	51-200	Link
Aurigo	Masterworks	Project and budget management, resource and material tracking, approval of testers and materials, forecasting based on available resources, reporting via project dashboards, integration with Microsoft SharePoint and AASHTOWare products.	201-500	Link
ExeVision	Integrated Project Development (iPD) Web	Sample management, material definitions and attributes definition, tester certification and qualifications, facilities inspection, inventory management, equipment tracking and calibration.	11-50	Link
Headlight	Materials Program Management	Sample logging, sample tracking and verification, real-time information sharing, access for internal and external users.	51-200	Link
Synaptic Sci	Lab Sci	Sample logging, sample tracking and verification, test tracking and logging, data sharing.	11-50	Link

On April 4, 2023, MassDOT issued a request for information (RFI) to vendors that offer LIMMS products for purchase. The RFI outlined LIMMS product requirements including scalability, security, sample tracking and management, compliance and regulatory support, a

user-friendly interface, and data acquisition capabilities, among others. Nine vendors responded to the MassDOT RFI, including the five vendors listed in Table 3.3. The additional four vendors are Thermo Fisher *(89)*, Autoscribe Informatics *(91)*, Quality Systems International *(92)* and HaulHub *(93)*. Table 3.4 presents architectural details of the products offered by these vendors. All of the listed LIMMS have the capability to store data in the cloud. From 2018 until 2023, MassDOT used a LIMMS created by ATSER *(94)*. The web-based Assure-IT Quality Management System provides supplier and contractor management, tracking and controlling of approved mix designs, personnel certifications, and non-conformance tracking, among other functions. The system was limited by slow response time and inflexibility.

Table 3.4: Summary of additional LIMMS vendors

Company	**Suite**	**Capabilities**	**Emp. count**	Ref.
Autoscribe Informatics	Matrix Gemini	The LIMMS system includes an application programming interface, instrument calibration and configuration for testing and test data acquisition.	51-200	Link
HaulHub	N/A	HaulHub system uses Amazon Web Service infrastructure and can be accessed by users through IOS, Android, and web applications.	11-50	Link
Quality Systems International	WinLIMS	Microsoft ASP.NET-based web application. A three-tiered system that includes data layers.	11-50	Link
ThermoFisher	SampleManager	LIMMS software has a multi-tier architecture with a thin client (web or desktop), application server and web service, and database offering integration with mobile applications.	10,000+	Link

** ThermoFisher size is the size of the entire company

3.1 Summary of ATSER Limitations

This section provides a description of the limitations of the previous MassDOT LIMMS system provided by ATSER. This information was collected from the MassDOT LIMMS Steering Committee.

3.2.2 Administrative Features

In the area of administrative features, the ATSER software was found to be lacking in several areas. It was difficult to customize the appearance of web pages, including the main landing

page, to user preferences. In many cases, unnecessary or unneeded information was displayed. For example, sample entry pages often contained fields that were only relevant for selected sample types. These pages could not be changed, even with administrative access. The software was also criticized for its protracted data access times. In some cases, users were locked out of the system for 30 minutes or more following a password reset. Furthermore, users reported that the system was prone to frequent downtimes, which resulted in dashboards failing to load.

3.2.3 User Experience

While the design of the ATSER user interface was generally well received, users reported that its use required extensive training and its overall format was not intuitive to use. The software was also criticized for its slow data access times. On a positive note, users appreciated that the LIMMS system did not require a virtual private network and minimized the use of paper.

3.2.4 Reporting

Reporting was identified as a weak point of the ATSER software. Reports generated by ATSER were described as excessively lengthy and occasionally missing crucial information. There also was no way to generate ad hoc reports. However, users appreciated the LIMMS system's ease of exporting data into Excel for reports.

3.2.5 Test Methods

Users reported concerns that some tests were not supported by the ATSER software. The addition of tests required administrative support at an additional cost to MassDOT. A desired feature for the new LIMMS product is the ability to link testing at multiple locations.

3.2.6 Inspection and Sampling

The ATSER software was commended for its ability to track samples and distribute test results. However, users expressed a need for the new LIMMS product to support multiple contracts which use representative sampling and split sampling.

3.2.7 Non-compliance Reporting

Users reported difficulty in sharing NCR forms with external individuals. The contractor/producer/manufacturer would be contacted by email to respond to the NCR, and then their response would have to be transferred to LIMMS. NCRs were identified as a feature that needs significant support in the new system.

3.2.8 Security

MassDOT Information Technology (IT) identified the potential for the ATSER system to be hacked due to low security standards. ATSER failed penetration tests just prior to go-live, and only deployed a patch to resolve security issues. Users identified the need for two-factor

authentication in the ATSER software and expressed a preference for multi-factor authentication in the new LIMMS product.

3.2.9 Miscellaneous

The ATSER software was criticized for inflexibility. ATSER staff often needed to be contacted for small software changes. Users also expressed a desire for the construction system (currently Transportation Information Superhighway (TISH)) to be integrated with a new LIMMS. TISH was integrated with the ATSER LIMMS. Contract information was populated to the RMS360 via TISH from Site Application Module (SAM) and Contract Management System (CMS).

3.3 Comments from MassDOT Interviews

3.3.1 Steering Committee (March 30, 2023)

On March 30, the UMass team met with the MassDOT LIMMS Steering Committee to discuss these issues. Some of the information provided at the meeting included:

- It should be easier to input and track samples using LIMMS. The current system requires many menus and is not easy to use.
- There should be more choices for administrative control. It is difficult to restrict data access and to customize feature access.
- The new system should continue to interface to legacy systems (SAM, CMS, SharePoint, and ProjectInfo). These system include contract information and vendor data.
- Improved reporting and dashboards are needed. The current dashboards are not flexible or customizable.
- Web-based interfacing is preferred. Some use of an asynchronous restful API may be helpful. The use of portable tablets and phones may be useful although most data entry would continue to be performed at a PC in a laboratory.
- It would be desirable to be able to customize the LIMMS software using plugins. These interfaces should require minimal programming skills.

The UMass team expressed significant concern about the ability to migrate information from the current ATSER LIMMS to a new system. MassDOT representatives indicated that ATSER data has been saved in text files and Excel sheets in an effort to preserve the current status of materials testing.

3.3.2 District Materials Engineers and District Quality Engineers (May 2, 2023)

A one-hour interview with MassDOT district materials engineers (DMEs) and district quality engineers (DQEs) was performed on May 2. Both groups emphasized the need for LIMMS usability. Attractive points of the previous ATSER system include the ability of engineers to track samples, distribute information, and create logs. The engineers noted that ATSER reporting was quite poor, a common theme through multiple interviews. For example, it

would be desirable to know what additional testing is needed to complete a contract and what testing has already been completed. In general, it was felt that ATSER LIMMS data entry was not intuitive and not geared towards inspectors. Other important points raised during the interview included:

- New software should have an interface to TrackIt for contract documentation and RMS360 for evaluative purposes.
- Materials quality reports should be available across districts.
- Reporting should be configurable and flexible.
- It should be possible to update specifications at least once per year.
- Smart phone / Microsoft Surface input would be desirable. It would be desirable to be able to add photos to sample information.
- The software should be accessible to contractors for their use.

It was also mentioned that non-compliance reports (NCRs) should be supported. Overall, this interview provided valuable information regarding requirements for a next generation LIMMS.

3.3.3 Laboratory Technicians (May 4, 2023)

A one-hour meeting with MassDOT laboratory technicians was conducted on May 4. Some of the described negatives of the previous ATSER LIMMS included:

- Test reports were not comprehensive and took a long time to access.
- It was impossible to fix simple specification and data errors in the system without involving the software vendor.
- Some sample test information was missing after data entry.
- System administration was very limited.

Suggested features for a new LIMMS included:

- An interface to Horizon software used for concrete and compressive testing should be included.
- Functional dashboards should be integrated into the system.
- The ability to use LIMMS on a smartphone or tablet would be desirable.
- NCR tracking and resolution are needed.

Many of the comments from the technicians echoed comments previously received via written requests. There was consensus from the DMEs, DQEs, and technicians that LIMMS should be integrated with construction management software.

3.3.4 Client Administrators (May 16, 2023)

The one-hour meeting with client administrators mostly provided details of features that could be added to the new LIMMS

- LIMMS support for different user roles was identified as an important feature.
- NCR support is critical.
- Sample testing performed at multiple locations should be linked.
- LIMMS support in RMS360 is needed. This information could focus on bids and sample quantities.
- Reporting should allow for user-selectable categories. It should be possible to add vendors.
- The next LIMMS should have support for better training.

3.3.5 Information Technology Personnel (June 14, 2023)

A one-hour meeting with IT security personnel took place on June 14. The conversation covered IT security concerns regarding a new product and some of the IT requirements. Important points included:

- The previous ATSER product was not considered secure from an IT perspective and was generally isolated from other MassDOT software products.
- LIMMS software must undergo penetration testing on all platforms (desktop and mobile) on a regular basis. Vendors are often asked to provide information from a third-party security testing organization.
- Logs of computer access are needed. Often a third party maintains the logs.
- Data connections from local machines to a centralized server must be made using industry best practices. For MassDOT, this often involves an approved application programming interface (API).
- A software bill of materials (SBOM) is needed for all new software systems with descriptions of functionality for all parts.
- A data chain of custody must be apparent. Dual-factor authentication is often used. This typically involves Microsoft Authenticator.
- Microsoft Edge and Google Chrome are the preferred browsers for compatibility with new software.

3.3 Vendor Information from Interviews

To better understand available LIMMS products and their usage, interviews and demonstrations with representatives of the five companies listed in Table 3.3 and Thermo Fisher were conducted during August, September, and November 2023. Additionally, Zoom interviews with nine DOTs were conducted to better understand their recent experience with commercial LIMMS products. The following information summarizes salient points from these meetings for the six LIMMS.

3.4.1 Headlight

Information about the Headlight LIMMS was obtained from a company representative and employees of the Rhode Island and Louisiana DOTs. The Headlight LIMMS can be accessed via a web-based interface or a mobile application. The LIMMS database is hosted by Amazon Web Services (AWS) and data can be downloaded locally on a periodic basis. The database for the Headlight LIMMS is supported using structured query language (SQL). In general, the Headlight LIMMS requires customization on a per-DOT basis. A standard off-the-shelf product does not exist. The system provides a series of pop-up menus in a web environment, although iPads are also used by inspectors to enter data. In Rhode Island, iPad usage for construction tracking has been well received (over 90% of personnel use the Fieldbook app). Forms for the system can be filled out using a web browser on a PC or using an iPad and over 40 construction forms are now available. The mobile interface supports a restful application programming interface (API). Data can be entered when internet access is not available. The data is then synchronized with the web-based database when internet access is restored.
Menus are available for users to add comments and photos to samples and to sign off on test plans. Dashboards summarizing sample and test data can be customized. Information about samples can be made available to contractors and materials can be tied to specific contracts. There is not a direct interface that can be used by contractors. Logins by users with different privilege levels are supported. The CloudConnect product can be used to share LIMMS data with Microsoft SharePoint applications.

Sample information can be autopopulated; information for a new sample can be created using data from a previous sample (duplicate forms). The system includes support for NCRs. An out-of-spec sample can be accompanied with a sample plan checklist that will allow it to be moved back into compliance. One nice feature of the system is the use of Google Maps to identify where sample information is recorded. Overall, it is easy to create samples and reports and a number of useful dashboards exist. Users can fix incorrect sample data themselves. Sample testing and approval by multiple labs is not supported although the functionality may be added in the future.

3.4.2 SynapticSci

Information about the SynapticSci LIMMS was obtained from a company representative and employees of the Maine DOT. An attractive feature of the LIMMS is its close association with Microsoft products (e.g., Excel and Teams), including SharePoint interfaces. System data is hosted on Microsoft Azure using PowerPlatform in a Cosmos database format. Copies of the data can be stored locally, although this feature is not currently activated for Maine DOT. Two-factor authentication for login is not currently supported. The LIMMS inspection application works on mobile device and stores answers to a series of inspection queries. Display aspects of the LIMMS software, including the mobile interface is configurable without the help of SynapticSci. LIMMS data is visible across multiple districts in a state DOT. With appropriate permission, state contractors can also see data. The Power BI platform from Microsoft provides a graphical user interface (GUI) for the software. During a demonstration, this interface was used to develop a bid item and a sub-bid item (concrete). Row data located in the Azure database was used to populate forms and manipulate the data.

A comprehensive set of data export options are available in the system. Local administrators can easily modify the format of the Power BI GUI as needed and create new expressions for samples and tests. The system can handle many different scenarios and has mobile functionality. Reports can be accessed via Microsoft Access.

During the automatic setup of tests for samples, the user has specific roles and authorizations and is provided a configurable view of sample information. Custom test pages can be created by administrators. Status information for each sample can be shown graphically and the system supports bar code and QR code scanning for samples. A sample can be located by test or sample number. Bid items can be used for multiple projects. Items can be marked and specific categories of components can be displayed. Options can be set to prevent modification of test information following entry. Engineers across multiple districts can access data via Microsoft connectors, a type of software interface. The view of sample information in a web browser can be customized and completed tests can be shown. Non-compliance reporting is supported and associated samples can be retested and tracked. The NCR form has a "related" tab that can lead to additional information. NCRs can be set by test or sample number. Search fields for data are customizable. It is possible to search by priority and category. A timeline of actions is provided for samples that are undergoing tests. Samples can be grouped together.

3.4.3 Aurigo

Information about the Aurigo LIMMS was obtained from a company representative and employees of the Utah DOT. The Aurigo product is cloud based and uses the Masterworks cloud application. Data is stored via AWS and a local copy can be downloaded every few hours. The system allows for measurement against standards and suppliers can enter information about materials directly. Often, these suppliers have different permission levels. The system supports two-factor authentication for login.

A mobile application for data entry and access is available. A sample record can be created using a QR code via a mobile application. Out of spec samples can be noted. Reporting allows examination of specific items in a project or contract. Samples can easily be associated with tests and a chain of custody can be determined. Sample records can be split into subsamples. Overall, the manipulation of materials sample records is straightforward. An individual can be assigned multiple roles. The software also supports non-compliance reporting. Compliance messages are generated automatically as testing occurs. Libraries are available for multiple specifications and data is entered in a per-field form. Sample usage can be tracked using a web-based form. Based on a demonstration, it appears somewhat difficult to generate specific reports. Data visibility is an issue and there is limited availability of dashboards. Aurigo must make any changes to the software.

3.4.4 AASHTOWare

Information about the AASHTOWare LIMMS was obtained from company representatives and employees of the New York, Michigan, and Connecticut DOTs. The AASHTOWare Project Manager (ACM) and older SiteManager products are widely used by these DOTs. ACM supports mobile data entry via MobileTester software. Data is stored by a private

company, Infotech, rather than AWS or Microsoft. The database is managed by SQL. Infotech also provides software maintenance and can make significant modifications to the software. It was mentioned that local administrators can modify data representations in the system and make minor changes to the software. Technicians can attach documents to sample records as needed. A software bill of materials is available for the product. A notable aspect of the product is its support for multiple Microsoft products (Authenticator, Azure ID, and a restful API for SharePoint). Data is transferred from a local site to the database via a secure dataloader. Authentication is performed based on defined user roles.

Significant technical support is available for the ACM product. An on-line forum exists that includes input from other state DOTs that use the product (e.g., Texas, Montana, and Nebraska). Helpful tools can be downloaded from a website and several levels of local system administration allow for interface customization. A positive aspect of the system is its support for more than 40 user roles. This feature allows contractors to have access to the system with limited capabilities.

Custom and basic sample and test reports can be generated. NCR and results generation are supported. It is easy to add materials in the LIMMS and multiple tests can be included on the same page for a single sample. NYDOT representatives seem satisfied with the reporting capabilities of ACM and numerous dashboards provide data access. A test queue dashboard was demonstrated, and other dashboards are available. It is also possible to generate a number of preprogrammed reports. These reports can subsequently be manipulated using Microsoft Excel. Workflows can be developed for individual lab units.

The ACM product has a set of graphical menus that allow for sample creation. Each sample is identified with a sample ID. Of note, it is possible to associate a contract with a specific sample. Sample information can be entered offline and automatically updated when internet access is re- stored. ACM supports many different roles which provides a variety of data views. Bar codes can be easily generated as sample data is entered. Associations between samples are directly supported. Default and optional tests can be created and the chain of custody of samples can be tracked. Test information is well organized. There are different levels of tests and samples included in the tests can be reviewed. Several DOTs indicated that sample data cannot be easily shared across multiple districts. One DOT felt that the mobile inspection application, which runs on tablets, is not that useful and generally is not widely used.

3.4.5 ExeVision

Information about the ExeVision iPD LIMMS was obtained from a company representative and employees of the New Hampshire DOT and Illinois DOT (IDOT). New Hampshire started using the iPD product several years ago. It was mentioned that a fully customized version of the product is currently being used. An off-the-shelf standard version of the product was unavailable when the New Hampshire system was first deployed. Such a system has recently been made available to other DOTs. The ExeVision product is focused on materials management. A mobile application (eFieldBook) is available for Android tablets. LIMMS data is stored in Microsoft Azure and IDOT has a local mirror site that is updated once per day. The possibility of using SharePoint to enter, store, and collate data is unclear.

DOT staff members can provide some administrative support for the ExeVision product. Software maintenance is generally provided by ExeVision.

It is possible to log samples in the field into the LIMMS using an iPad. However, many of the fields that must be filled can only be accessed by mouse right-clicks, making iPad usage difficult. IDOT is currently working with ExeVision to develop a workaround. It is possible to generate QR codes in the field and then fill in sample information later at a web-based computer terminal. The QR codes can also be used to generate reports and to query samples that do not conform to requirements.

Customized reporting is available using radio button selections on a menu. Templates can be used to store information for different sample types. Contractor access to data is not allowed. Testing data can be shared across multiple locations.

Information from samples can be copied and multiple samples can be entered at the same time. Custom test information can be made and access can be restricted to users with specific roles. Administrators can add test methods. Contract data from a construction database can be imported. A process for supporting NCRs was created for Vermont DOT. Test methods associated with individual samples can be documented with the system and tests can be associated with specific materials. It is possible to create new test methods without explicit support from ExeVision. Drop down menus are provided for data logging. The IDOT LIMMS system supports an interface to ELM software that is used to manage contracts. A ledger can be created to track the connections between contracts, samples, and tests. Individual samples can be located via a test ID.

3.4.6 Thermo Fisher

Information about the Thermo Fisher LIMMS was obtained from a demonstration by a company representative. Thermo Fisher offers the SampleManager LIMS product. Sample data is hosted in AWS and mobile and web access is possible. An administrator can define multiple roles for users. Samples can be labeled with QR codes and subsamples can be created. Sample information can be dumped into Excel. Overall, the LIMMS appears to be a small part of a much larger system and may be difficult to use as a standalone product.

3.4 Summary of LIMMS Capabilities

In this section, we summarize support for several important LIMMS features across the six LIMMS products noted in the previous section.

3.5.1 Mobile Device Support

All company products support mobile entry of sample information. DOT interviews indicated that the mobile interfaces for ExeVision and AASHTOWare ACM have limitations that effect their usefulness in the field. A demonstration of the Thermo Fisher mobile interface was not performed.

3.5.2 Interface with Microsoft Products

Products from AASHTOWare, Headlight, and SynapticSci offer effective interfaces to Microsoft products, including SharePoint and Excel. Microsoft support for the other products is either limited or unclear.

3.5.3 Non-compliance Report Tracking

All products support NCR tracking.

3.5.4 Support for Use by External Contractors

SynapticSci and AASHTOWare allow contractors limited access to the LIMMS via user permis- sions. Headlight and ExeVision's systems does not allow contractor access. It is unclear if the Aurigo or the Thermo Fisher LIMMS can be configured to support contractor access.

3.5.5 Customizable GUIs/dashboards

All products allow for some customization. The SynapticSci LIMMS indicates that GUI changes can easily be made using Microsoft Power BI tools.

3.5.6 Customizable reports

All products allow for user-customizable report generation.

3.5 Results of the MassDOT Workshop

The comments obtained from the groups in response to the three posed questions varied from very broad to very specific. In the following, major points stressed by multiple groups across multiple stations are noted. Detailed summaries for each station are located in subsequent subsubsections.

3.6.1 Summary of Findings

Integration with Existing Software Systems: All groups felt that the database associated with the new LIMMS needs to be tightly integrated with RMS360, Site Application Module (SAM), and Contract Management System (CMS). For example, sample and test forms should be auto-populated with information from RMS360 / SAM and specification information from AASHTO. As sample and test data is entered into the new LIMMS, it should be synchronized with databases in the other systems.

Landing Page: The LIMMS landing screen should have links to dashboards, projects, and contracts, perhaps using dropdown menus. Information on the login screen should be customized based on the user's job (resident engineer, technician, etc.). Project information should include a percentage complete for each project and an associated to-do list for incomplete projects.

Webpage Customization: LIMMS website interfaces for dashboards, reporting, and sample entry should be customizable by the user without the need for assistance from an administrator. Dashboard interfaces should have options for predetermined stock reports and user-customized reports.

Mobile Data Entry: Mobile sample and test data entry in the field was listed as a priority by many groups. Data entry could involve scanning QR codes or bar codes and/or manual data entry. The mobile interface for a tablet or smartphone should be similar to the web interface found on a PC.

Data Search: The sample and test dashboard should be flexible. Users should have the ability to search a database by sample type, bid item number, contract number, and other user-selected metrics.

Data Access: Permission to perform actions and access to forms and data in the LIMMS should be customized based on job roles. Contractors should have access to the LIMMS using this model.

Notifications and Alerts: The LIMMS should include notification and alert capabilities. Time-critical alerts and reminders should be automatically generated for actions involving samples.

NCRs: Non-compliance reports (NCRs) should be supported throughout all aspects of the new LIMMS. NCR support can include a web form, dashboard, integration with RMS360, and tracking across the database.

Support for Documents: The LIMMS should allow for the upload of scanned documents. Users should have the ability to search through stored documents.

Test Reports: The test report form should allow for customizable reporting. Reports should be compliant with Federal Highway Administration (FHWA) regulations.

3.6.2 Summary of Comments for Discussion Stations

Station 1: RMS360

There is a desire to closely integrate the new LIMMS with RMS360, CMS, and SAM. The appearance and use of the current RMS360 and how it could be integrated with these other platforms led to the following observations regarding platform characteristics:

Forms: A list of formatting items that could be addressed include the following:

- The use of acronyms in RMS360 is a challenge and all abbreviations should be defined in RMS360 and the new LIMMS.
- The dual use of form columns for RMS test form numbers and documentation abbreviations (COC – certificate of compliance, INSP – inspection) is confusing.
- Clicking on a requirement should bring up the needed form. This feature could be integrated into the new LIMMS.

- RMS test form numbers (and their use in the new LIMMS) could be replaced with descriptive words.

RMS360 Enhancements: Participants indicated that they would like easy access to bid items, descriptions and requirements, and specifications. A bid item should indicate the required documentation for testing and any special contract provisions. Bid items and materials information should be updated automatically with a manual override. Ideally, sub-items are automatically added to bid items. It may be beneficial to access bid items using words rather than numbers.

A clickable specifications link, including information from AASHTO, should be available per sample. Specifications should be accurate, and it should be possible to update them, if necessary. There should be links from the sample record to specifications in RMS360. Special conditions for the sample can be flagged. The system should include the ability to notify inspectors of the samples they are required to obtain. RMS360 should include a link to the Qualified Construction Materials List (QCML) website. The website information could be integrated into RMS360. It was suggested that the name "Materials Requirements System" might be more appropriate than the current RMS360 name. Contractors could be given access to RMS360 and the ability to upload documents.

RMS360/SAM/CMS Interfaces: It would be desirable to cross reference pay slips in SAM with materials requirements in RMS360. Quantities in RMS360, SAM, and CMS should synchronously update with data from the LIMMS. For a project, it may be possible to project the number of required samples and provide the information in a report.

Requirements: Following approval, only quality assurance personnel and DMEs should be able to update RMS360 and LIMMS values for samples. All changes should be clearly documented (what was changed, who changed it, when it was changed). It should be possible to add contract documents to requirements, such as a quality control plan.

Reporting: RMS360 should provide notifications via LIMMS about completed requirements. It should be possible for RMS360 to automatically determine when requirements are completed. Completed and verified bid items should be shown on the RMS360. Completed bid items could be shown in green or with a check mark. For each project, contract requirements, district requirements, and percent project completion, including sample quantities and test progression, should be noted.

RMS360 Data: It would be desirable to link a RMS360 test form number to the associated test card. Clicking the link will access the card. It should be possible to modify items for special provisions, and add extra work orders (EWOs).

RMS360 Interface: RMS360 columns should include the number of samples required versus the number of samples completed. RMS360 columns should include estimate quantity versus actual quantity to date. Side-by-side columns in RMS360 are preferred. It may be possible to filter out bid items with no materials required.

Station 2: Sampling

The organization and use of sampling information form important parts of the planned LIMMS. The following information provides insight into how this information could be entered, presented, and searched:

Interface: The sampling web interface should look like the forms that are currently in use. Some of the sample information that must be entered is required under AASHTO specifications. Where possible, the number of default fields for sample entry should be minimized. Samples should be identified by contract number, bid item, and sample type with producer information available from a log sample screen. Sample tracking can be located on a different page. Helpful popups could be included on the log sample screen. There should be LIMMS support for samples with multiple specimens and the ability to perform sample look up and create samples using a GUI. The name of the person who took the sample should be included with the sample information. The sample web interface should be customized by the user (by access level or user preference) and test methods should be shown on the sample page. Information should scroll vertically rather than horizontally.

Workflow and Training: It should be possible to support workflows for sampling. Any implementation for LIMMS sampling (or other parts) should have training materials included.

Mobile LIMMS Usage: There is an immediate need to scan and log samples remotely (especially for concrete). The implementation could include printable decals for samples. QR codes, bar codes, and/or sample numbers could be used. Bar codes may be more useful since QR codes can become smudged. Regardless, a sample number interface must appear in the mobile LIMMS application. There is a benefit to having a mobile sample entry interface that appears similar to the web interface. If RFID tags are to be used, appropriate reader technology is needed for field use.

Interaction with RMS360/SAM/CMS: The sample entry web interface for the new LIMMS should allow a user to search for a sample via contract number, bid item number, and sample type. Information should populate automatically from RMS360, SAM, and CMS. Each sample should have a unique sample ID. The producer of the sample can be located via a dropdown menu. This menu could also include the names of the distributor and the manufacturer. SAM should be able to automatically update RMS360 and should include how many samples were taken. A bid item number can be used to access RMS360.

Tracking and Information Access: Sample tracking should include a chain of custody. Sample counts for a job should be provided. A user should be able to configure menus and reports without administrative intervention.

Time-based alerts: The LIMMS should support time-based alerts and reminders for samples.

Station 3 - Testing

Sample testing is integral to sample validation. The following suggestions were made to integrate testing into the new LIMMS.

Initial Screen: There was significant discussion around this topic. Some attendees felt that a tester should log directly in to a test-specific screen, while others felt they should see a dashboard that represented different modules. Everyone agreed that the process should require as few clicks as possible.

Test Organization: There were many different views of how this should work ranging from an IT-inspired ticket system, to a more simplified tabular view that could be sorted according to sample type, test type, or bid item. Some tests have dependencies and need to be performed in order so a progress bar across linked tests would be useful. Other tests have a critical time component where a test needs to be performed within a certain number of days after it was collected.

Split Sample Testing: There was not a huge amount of discussion on this topic, but it mainly pertained to the types of technologies used to track samples. Currently RFID is used, with some fear that the vendor that supplies the tags may go under. Split samples are currently implemented by assigning new sample numbers that link to a parent sample that was collected in the field.

Test Sign-off: There was a significant desire to streamline this process. Many materials pass tests. There should be a batch approval process for the tests that pass, while the ones that fail can be handled individually with supervisor comments that would be incorporated into the non-compliance report. From a security standpoint, a digital signature system should be adopted for supervisors to certify test results.

Test Data Revision: This item was discussed amongst several teams. One idea was minimizing the likelihood that garbage data could be captured in the first place by not allowing values significantly out of range to be accepted (i.e., breaking the laws of physics) or forcing confirmation for values that do not fall within specification. There was contention between testers and supervisors over whether or not a tester should be able to directly update data or if the update should be completed by a supervisor.

Updating Specification Requirements: This was addressed as ensuring that material types inherit appropriate tests from bid items. The requirements for the same material can vary significantly, depending on the context in which they are used. Some attendees commented that this is a feature that could be easily abused to make a sample pass a test.

Assigning Tests to Sample Types; Inactivating Unnecessary Tests: There was significant interest in having a system where an auto-assigned suite of tests is assigned to a material based on the bid item. This would prevent clutter with auto population of irrelevant tests. Tests could be added or removed on a case-by-case basis. The old ATSER system resulted in a lot of empty fields and clutter.

Tracking Version History: This was discussed informally. There was a lot of debate about the statistical significance of tests and it being inappropriate to re-test borderline samples until they passed. Everyone desired some autonomy to re-test borderline samples. There is also a desire to have four different status values for tests including 'pass', 'fail', 'repeat', and 'FYI'. Pass and fail are self-explanatory, with a repeat being a special version of 'fail', meaning the outcome was not clear and a repeated test was needed. The FYI status can be used during training so that entered data does not pollute existing data.

Miscellaneous: One attendee pointed out that there is a fundamental difference in testing a sample that comes from a plant versus one that comes from the field. This might even necessitate an optimized workflow. Another attendee indicated that only two types of tests are ever run at their facility, one in the AM and another in the PM. This might also warrant an optimized LIMMS interface.

Station 4: Documentation

Discussion at this station focused on responses to three questions posed at the beginning of the workshop. Summaries of the responses are as follows:

What information is needed by technicians and engineers to do their jobs? The information provided at this station echoed feedback received elsewhere. The following list was compiled:

- There is a desire to have contractors upload documents into the new LIMMS much like they currently do in project control sites. Document uploading should be supported for all parties in the new LIMMS.
- Close interaction between RMS360, SAM and the new LIMMS is vital. Data should be automatically synchronized between these systems.
- The dashboard for each project should indicate how much of each job (specified by bid item number) is completed and how much job documentation has been completed.
- The new LIMMS should use the bid item number available in RMS360. A customizable interface should be available to allow for searches by bid item number.
- The LIMMS interface should be able to provide a view of only those projects that are outstanding.
- Links to specifications, including those provided by AASHTO, should auto-populate on sample and test pages.
- Workflow processes should be automated.
- Quick links should be available for test cards and bid items.
- A search bar for projects, documents, and data is needed.

What information should be located on the login page for engineers and technicians?

- A list of bid item numbers and job completion percentages should be provided.
- Upon login, the user should be given the option of migrating to the web-site location of the last log-out.
- The login page should include a dropdown menu of dashboards.

- It should be possible to limit the number of contracts that are shown based on user selection.
- Test result filtering per contract is needed. Data filtering should be included in the new LIMMS. A certificate of compliance (COC) should be good for an entire job and should be used for multiple sections of a job. It should be possible to restrict data access to the current district but allow for access to data from other districts. The system should support alerts and reminders about samples.

What features could you use right away?

- Data in all systems (LIMMS, SAM, CMS, etc.) should automatically synchronize.
- All items for a specific job should be included per bid item number.
- Non-compliance report (NCR) tracking is needed.
- For each project, a to-do list of items needed for a project should be provided.
- Cross-project links for samples of similar materials should be available.
- Support for scanned documents and document search is needed.
- Embedded interfaces to SAM and RMS360 should be provided.

Station 5: Reporting

The following is a summary of information related to reporting.

Individual Reporting and Data Management: There is a need for the LIMMS to offer detailed reporting capabilities that are specific to individual sample types, manufacturers, and specifications. The system should allow users to visualize historical data to derive insights for future steps and manage data granularly for in-depth analysis and export purposes. Furthermore, the system should be able to merge and centralize information sourced from a variety of software and facilitate the communication of important report results to contractors, including digital signature prompts.

Streamlined Reporting and Quality Control: Individual reporting processes within the LIMMS should be simplified. A single-page report design that would present only essential information to expedite quality control processes is a possibility. Clarifying reasons for sample rejections and communicating subsequent procedures should be presented. An alert system is needed to manage critical issues proactively and the LIMMS should offer clear visual representations of a sample's lifecycle by linking various data sources. The system should be accessible via mobile devices, allowing for decision-making on the move, and capable of generating reports with minimal user interaction.

System Integration and Automatic Calculations: Different systems and automation should be integrated within the LIMMS to streamline workflow and improve efficiency. The automatic calculation of key metrics (such as percent within limits) and the triggering of related actions within the system (such as payment or further calculations/sampling) would be beneficial. A sample life cycle should be integrated into a single system to ensure continuity and clarity of processes. Controlled access for contractors, with specific privileges for system interaction to maintain data integrity and security, is recommended.

Customization and Compliance: The system should allow users to adjust reports before finalization and to customize the visibility of information within the reports. A clear assignment of tasks, with explicit timelines for each project and sample, is particularly important. The system should enable the linkage of specifications to forms and provide separate modules/calculation sheets for data verification, as well as the consolidation of tests for a sample.

Compliance and Data Exports: Reporting should be compliant with FHWA requirements. The LIMMS must be capable of filling out and securing mandatory report forms and should be equipped to initiate NCRs and related task assignments. The system should provide different data views tailored to various user roles, all connected to the primary report forms. Furthermore, the final report form should be locked to prevent unauthorized changes and it must also facilitate data export when necessary.

Other observations: The insights gathered from the workshop illustrate some of the essential functionalities for MassDOT's proposed LIMMS. The participants collectively highlighted the importance of several core features, all of which are vital for creating an intuitive and regulatory-compliant system that summarizes all relevant information in one platform. Discussion at the workshop led to the following list of LIMMS reporting requirements:

- Comprehensive Life-Cycle Visualization: The system must offer a detailed visualization of the life cycle for each sample and project, allowing for a clear understanding of progression, outstanding tasks, and timelines.
- Compliance with Standards: Ensuring that the system aligns with FHWA requirements and other regulatory standards is important. The LIMMS should manage compliance-related documentation and processes.
- Automation of Routine Processes: Automatic calculation of compliance metrics and intuitive triggers for subsequent actions are necessary for streamlining workflow.
- Integration of Data and Systems: A singular system that integrates various data points and platforms will prevent the need to shuffle through different software, providing a linear and clear progression for each sample's life cycle.
- Customization of Reports and Information: Users should be able to customize and alter reports, making adjustments prior to finalization and controlling the visibility of information.
- Task Management and Actionable Steps: Clear task assignments, timelines and step-by-step guides for project samples should be provided, indicating responsibility, and ensuring progress tracking.
- Mobile Accessibility and User-Friendly Interface: Reports should be accessible and easily interpretable on mobile devices, supporting quick decision-making processes.
- Data Security and Role-Based Access: Different levels of access and information views must be defined according to user roles, with stringent controls over contractor interactions.
- Streamlined and Efficient Reporting: The system should enable the generation of simplified, one-page reports that present only the essential information required for quick assessments and decisions.

- Visualization and Multiple Queries: Advanced data visualization tools and the ability to handle multiple queries (based on a certain mix, requirement, contractor, etc.) for generating comprehensive reports and tables are crucial for in-depth analysis and strategic planning.
- Alerts and Notifications for Quality Control: An alert system for flagging out and escalating information will facilitate proactive quality control and issue resolution.

Station 6: Interface

The following is a summary of information from the interface station.

Landing Page, Design and Layout, Functions, and Modes of Use: The landing page should be customizable by the user and based on different employee roles. The page should show bid items for an employee (e.g., resident engineer) with a notation for outstanding items. A list of tasks (organized by contract number and bid number could also be included (e.g., for a resident engineer). An interface to RMS360 could be included on the landing page with a list of contracts made available via a dropdown menu. Contracts can be organized and ranked by number and can include bid item numbers. There should be flexible ways to assign field staff on the landing page. The page should ensure that all information is available on a single pane. Templates for different roles (resident engineer/field/external, etc.) are desired.

Additional Suggested Pages: The landing page is page 1

Page 2. Quality assurance bridge – Quality assurance information should follow the appearance of FHWA requirements.

Page 3. Active contracts – This screen will display what has been assigned to the roles.

Page 4. RMS360 – This screen will display links to requirements and documentation.

Page 5. Sample screen – Home page for creating and tracking samples. The page allows for automatic assignment of roles for samples transferred from the field to a district.

Page 6. Receiving screen – Information related to receiving samples.

Page 7. Test method screen – Provides information about test methods, digital signatures, and test result determination.

Page 8. Reporting – Dashboards available for report assignment.

Design and Layout: Vertical design (scroll down) and linear operation (drill down menus) should be followed. Flexible filtering is important. All unnecessary columns (e.g., GPS) should be in separate sections for forms. Autoscaling to fit all the content in different platforms (e.g., PC, tablet, phone, etc.) should be available. Administrative roles should have a separate layout to facilitate functions such as role privilege management (critical functions, but only a few have the authority to access them).

Functions: Auto-scaling for different devices is important. A sensible permission model should be built behind the scenes. It should be ensured that the data's granularity is preserved. The new LIMMS should serve as a repository for contractors, with MassDOT's supervision and review (all following RMS360). Each role should have a dashboard template and be customizable without needing to ask IT administration. Feedback functions should be provided. In testing pages, windows popouts (or side-by-side split windows) should be provided, and both windows should be editable, which is an important function for sample testing. In any tabulated data view, flexible filtering functionalities are desired. The synchronization function is important (especially across different modules). All data should be updated if it is edited in one location. The availability of a search function for data and documentation is critical.

3.7 New LIMMS Product Recommendations

The following summarizes product recommendations:

3.7.1 Administrative Features

Users expressed a strong preference for more administrative rights and the ability to make change choices in pull-downs in the next generation LIMMS. There is also a need to modify test method specifications as standards are revised, create new test methods or revise test methods without assistance from a vendor. Users also want the new system to support improved training, possibly including videos and a user manual.

3.7.2 User Experience

The new LIMMS product should be easy to use and adaptable for many different site types. The product should be intuitive for many different user types and abilities. Users also expressed a desire to use the new LIMMS product on tablets and smartphones.

3.7.3 Reporting

Users expressed a preference for user-selectable categories and columns in the new LIMMS product, as well as the ability to perform queries and searches.

3.7.4 Test Methods

Users expressed interest in support for plug-ins in the new LIMMS product. It should also be possible to populate a test entry with the data from another test to minimize data entry. It should also be possible to split samples to be tested at more than one laboratory. A test plan for outstanding materials is needed in the new LIMMS. Final reports should only include materials associated with specific contracts.

3.7.5 Inspection and Sampling

Sample logging should be simple and straightforward in the new LIMMS. Customizable dashboards and search menus would also be desirable.

3.7.6 Security

A secure communication protocol and multi-factor authentication are needed in the new LIMMS product. Users emphasized the need for secure communication protocols to ensure the integrity and confidentiality of data. They also highlighted the importance of having a clear chain of custody for data, with versioning used to track who made approvals. The importance of software modularity and the ability to patch and secure all software, including PC, tablet, and phone applications were also stressed. Geoblocking support and ADA compliance were requested. Finally, users expressed a need for a software bill of materials for the new product, including a list of libraries used.

3.7.7 Miscellaneous

Software modularity and the ability to modify screens in the new LIMMS product were highlighted as needs. Software should be patchable and secure.

4.0 Implementation and Technology Transfer

The workflow consists of multiple screens that can populate test data. Each of these screens prepopulates sample data using available contract and bid data for the corresponding material type. Each material has its own workflow with custom fields relevant to that material. Figure 4.1 shows an example of a sample record for concrete, Figure 4.2 shows an example of sample record for hot mix asphalt, and Figure 4.3 shows a sample record for structural paint. Existing contract numbers are pulled from an Excel spreadsheet that was imported to Microsoft Dataverse.

Each of the data entry flows for the three representative material types contains fields for data entry that are relevant to that material. Dropdown lists pre-populate as much information as possible to streamline information about the material, that does not result from testing by filtering possible suppliers by producer and location.

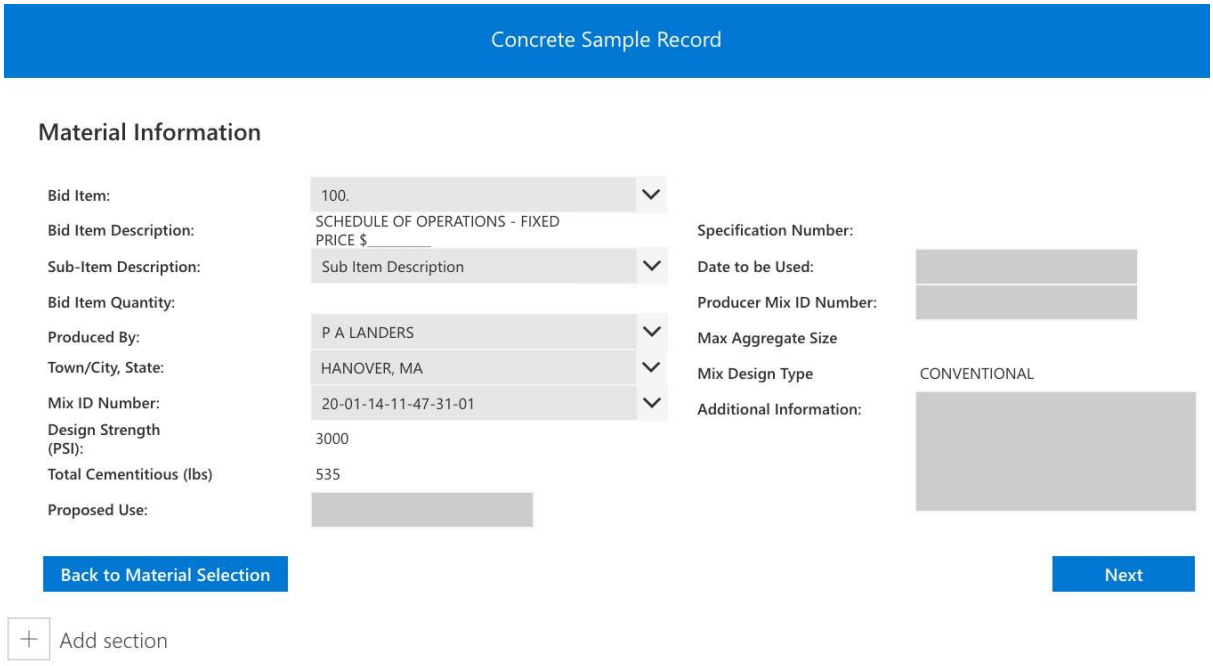

Figure 4.1: Sample record for concrete

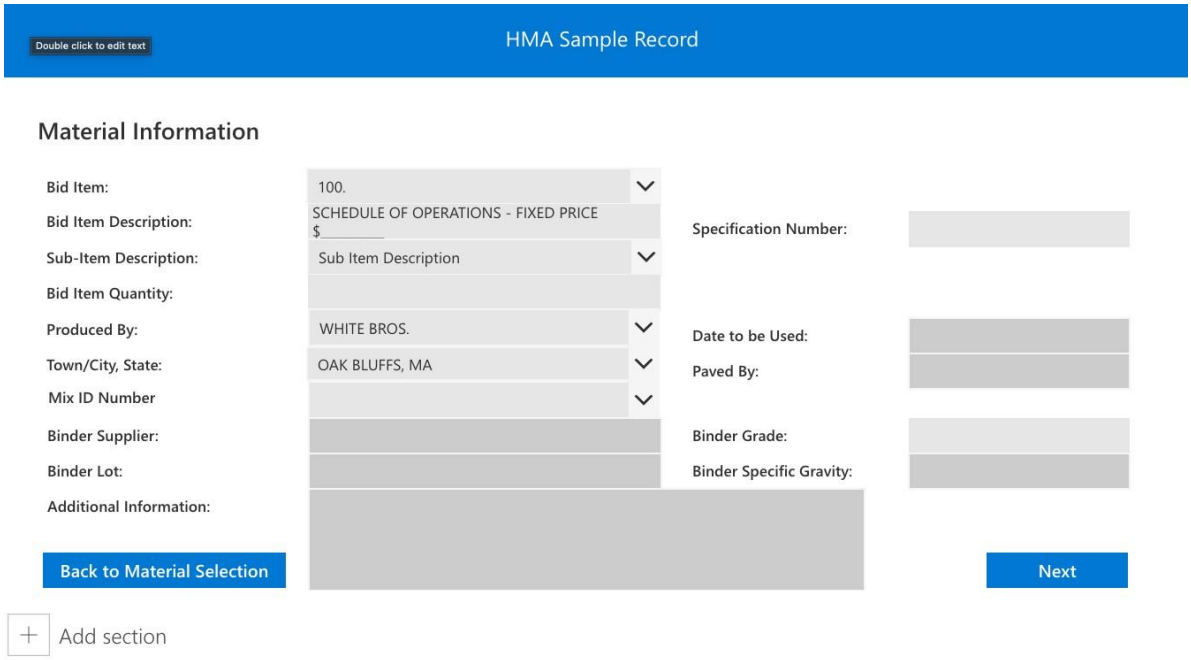

Figure 4.2: Sample record for hot mix asphalt

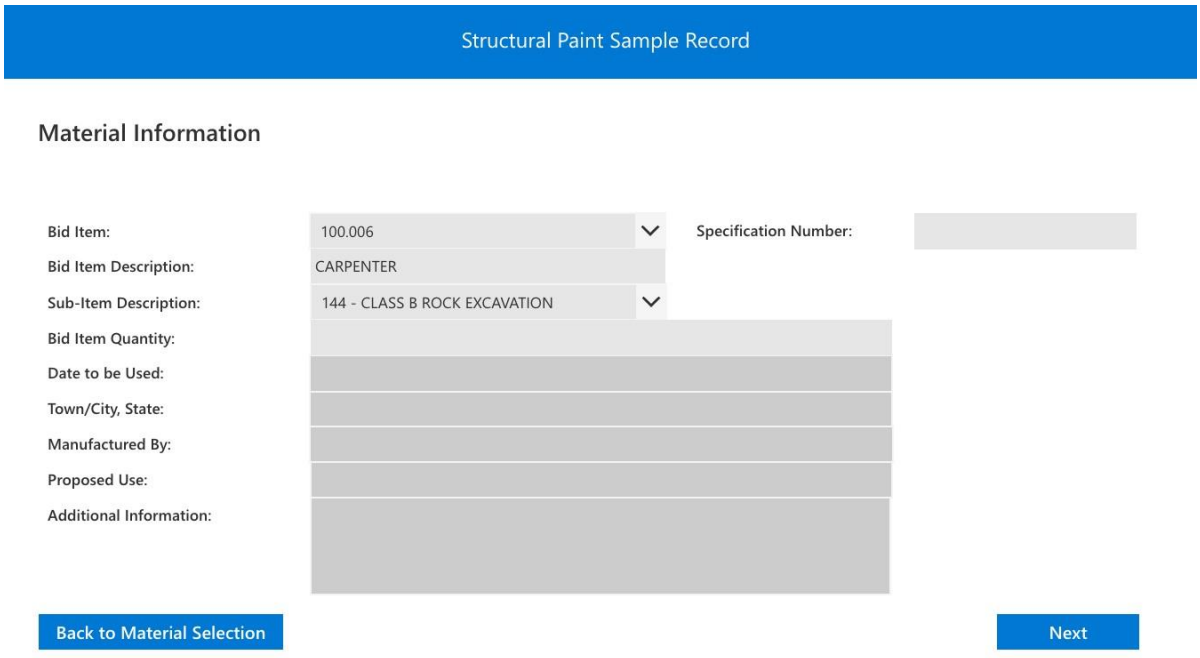

Figure 4.3: Sample record for structural paint

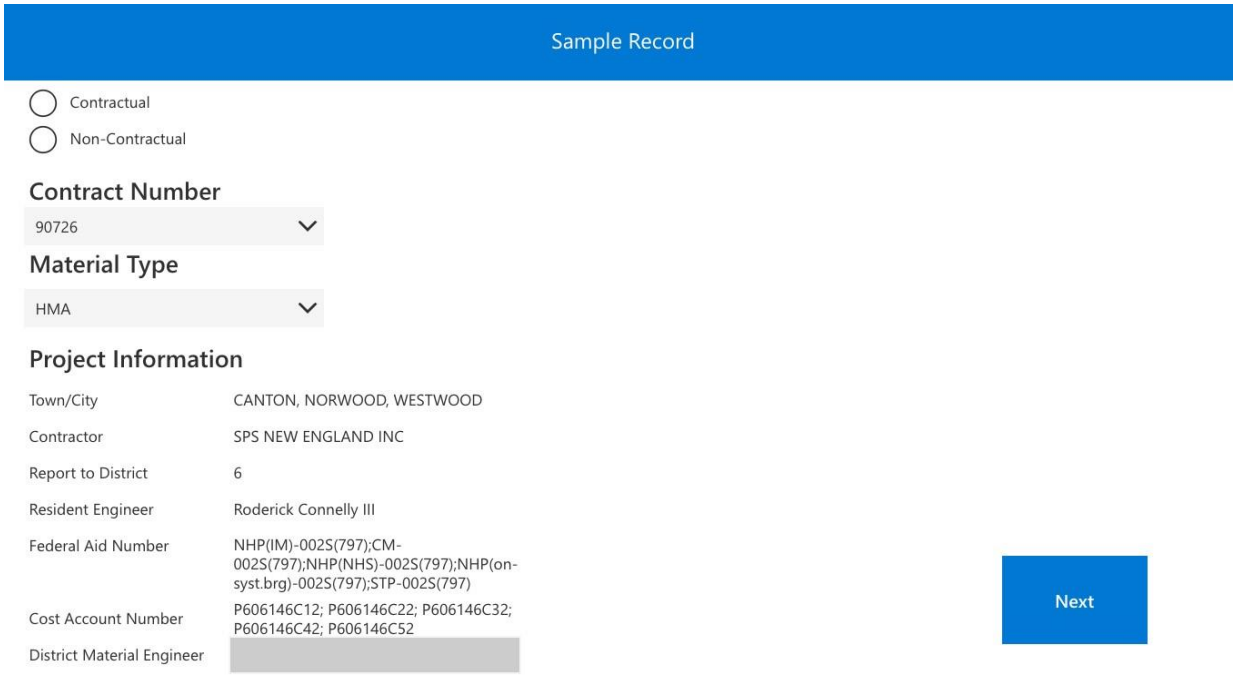

Figure 4.4: Start page for sample records

The start page for these samples includes a pulldown menu with information about the project. This information can be customized. An example start page is shown in Figure 4.4.

This page left blank intentionally.

5.0 Conclusions

In this section, we review the results of this study and offer conclusions on collected information.

This project involved a gap analysis of LIMMS products available for DOTs. A literature review of publicly available materials was performed along with interviews with MassDOT employees who use and maintain the LIMMS. It was apparent from the interviews that the LIMMS used by MassDOT from 2018 to 2023 was inadequate due to its inflexibility, slow response time, and lack of interfaces to other MassDOT software. It was often difficult to make minor adjustments to LIMMS interfaces without engaging the LIMMS vendor. There was also a significant charge by the vendor to maintain the LIMMS software.

Interviews with nine DOTs and six LIMMS vendors provided perspective on the state-of-the-art in LIMMS software. At least half the DOTs in the US use a LIMMS product based on AASHTOWare although many DOTs are transitioning from the SiteManager product to ProjectManager. This transition requires several years of effort and significant cost to complete. The wide use of AASHTOWare does allow for the sharing of modules and techniques prepared in-house between DOTs. A vibrant user community has evolved over the past few years. Although other commercial LIMMS are in use, notably ATSER, ExeVision, Aurigo, Headlight, and SynapticSci, many of these products are still in development and/or require significant per-customer customization. The initial costs and the costs of annual maintenance are also significant.

As mentioned in Section 3, MassDOT has decided to implement their own LIMMS, rather than purchase a commercial product. This choice has several benefits. First, the LIMMS software infrastructure can be directly customized to MassDOT needs and integrated with existing MassDOT software such as RMS360, SAM, and CMS. Interfaces to Microsoft products such as SharePoint, Excel, and the Power tools set are also desirable. Based on the interviews and analysis of commercial products outlined in this report, the following recommendations can be made.

Integration with other MassDOT software systems: It is important that all contract and materials sampling and testing information remain up to date to properly track project advancement. Many of the systems used by MassDOT interface to Microsoft SharePoint and use Excel for data collation. The new LIMMS should provide ample interfaces to SharePoint and allow for data sharing and synchronization across districts. Contactors should have access to some of the data via permission levels that are customized by administrators.

Customizable interfaces: The new LIMMS should allow for significant per-user customization, especially for graphical user interfaces (GUIs). In many cases, this customization could be performed by the user themselves via pull-down menus.

Mobile data entry: The new LIMMS should support mobile data entry by MassDOT employees in the field. Sample and test information may be entered without immediate internet access and automatically synchronized once access is re-established.

Customizable reporting: A major limitation of the previous MassDOT LIMMS was very limited support for customized reporting. Many reports included unnecessary information that was difficult to remove. The new LIMMS should prioritize reporting and allow for user-selected reporting of information via drop-down menus. Reports should meet Federal Highway Administration regulations.

Notifications and alerts: The LIMMS should include notification and alert capabilities. Time-critical alerts and reminders should be automatically generated for actions involving samples.

NCRs: Non-compliance reports (NCRs) should be supported throughout all aspects of the new LIMMS. NCR support can include a web form, dashboard, integration with RMS360, and tracking across the database.

Security: Existing LIMMS products have varied levels of security built in. Although most products support two-factor authentication, some do not. A benefit of developing a LIMMS in-house is the ability to customize security to MassDOT standards. Security solutions are needed for user authentication, data storage, and data communication.

Overall, LIMMS implementation should be performed incrementally and build on existing MassDOT software structures, including SharePoint. It is important that, once implemented, aspects of the system are not changed since user familiarity will be an important aspect of LIMMS acceptance. A detailed implementation schedule, including long-term maintenance, should be prepared to outline the progression of LIMMS implementation.

6.0 References

1. Federal Highway Administration. Transportation asset management plan annual consistency determination final guidance. https://www.fhwa.dot.gov/asset/guidance/consistency.pdf, (2019).

2. Massachusetts Department of Transportation. Transportation asset management plan. https://www.mass.gov/doc/2019-transportation-asset-management-plan/download, (2019). Accessed: April 8, 2023.

3. Alabama Department of Transportation. Transportation asset management plan. https://www.dot.state.al.us/publications/Maintenance/pdf/FinalTAMP.pdf, (2020). Accessed: April 8, 2023.

4. Montana Department of Transportation. Montana transportation asset management plan. https://www.mdt.mt.gov/publications/docs/plans/MDT-TAMP-2022.pdf, (2022). Accessed: April 8, 2023.

5. Alaska Department of Transportation and Public Facilities. Transportation asset management plan. https://dot.alaska.gov/stwddes/asset_mgmt/assets/TAMP.pdf, (2019). Accessed: April 8, 2023.

6. Nebraska Department of Transportation. Nebraska transportation asset management plan. https://dot.nebraska.gov/media/iqeffkxw/2022-tamp-report.pdf, (2022). Accessed: April 8, 2023.

7. Arizona Department of Transportation. Transportation asset management plan 2019-2023. https://azdot.gov/sites/default/files/2019/08/Transportation-Asset-Management-Plan.pdf, (2021). Accessed: April 8, 2023.

8. Nevada Department of Transportation. Fully-compliant transportation asset management plan. https://www.dot.nv.gov/home/showpublisheddocument/19776/637635071143000000, (2019). Accessed: April 8, 2023.

9. Arkansas Department of Transportation. Transportation asset management plan. https://www.ardot.gov/wp-content/uploads/2020/10/2019-ARDOT-TAMP.pdf, (2019). Accessed: April 8, 2023.

10. New Hampshire Department of Transportation. New Hampshire transportation asset management plan. https://www.tam-portal.com/wp-content/uploads/sites/12/2022/10/nh-tamp-2022.pdf, (2022). Accessed: April 8, 2023.

11. California Department of Transportation. Transportation asset management plan 2021-

2031. https://dot.ca.gov/-/media/dot-media/programs/asset-management/documents/2022-tamp-a11y.pdf, (2021). Accessed: April 8, 2023.

12. New Jersey Department of Transportation. New Jersey transportation asset management plan. https://www.state.nj.us/transportation/about/asset/pdf/NJ2019_TAMP_FHWA.pdf, (2019). Accessed: April 8, 2023.

13. Colorado Department of Transportation. Transportation asset management plan. https://www.codot.gov/programs/tam/transportation-asset-management-plan, (2022). Accessed: April 8, 2023.

14. New Mexico Department of Transportation. 2022 transportation asset management plan. https://www.dot.nm.gov/business-support/capital-program-and-investments/asset-management-bureau/, (2022).

15. Connecticut Department of Transportation. 2022 highway transportation asset management plan. https://portal.ct.gov/-/media/DOT/documents/dtam/Transportation-Asset-Management-Plan-FHWA-Certified-9302022.pdf, (2022). Accessed: April 8, 2023.

16. New York State Department of Transportation. New York state transportation asset management plan. https://tamptemplate.org/wp-content/uploads/tamps/071_newyorkdot.pdf, 2019. Accessed: April 8, 2023.

17. Delaware Department of Transportation. Transportation asset management plan. https://deldot.gov/Publications/tamp/pdfs/DelDOT-Transportation-Asset-Management-Plan.pdf, (2019). Accessed: April 8, 2023.

18. North Carolina Department of Transportation. North Carolina transportation asset management plan. https://connect.ncdot.gov/resources/Asset-Management/TAMP/Final TAMP - June 2021.pdf, (2019). Accessed: April 11, 2024.

19. Florida Department of Transportation. Transportation asset management plan. https://www.fdot.gov/docs/default-source/planning/tamp/TAMP-2015.pdf, (2015). Accessed: April 8, 2023.

20. North Dakota Department of Transportation. North Dakota transportation asset management plan. https://www.tam-portal.com/wp-content/uploads/sites/12/2023/02/NDDOT-TAMP-2022.pdf, (2022). Accessed: April 8, 2023.

21. Georgia Department of Transportation. Georgia Department of Transportation transportation asset management program. https://www.dot.ga.gov/GDOT/Pages/TAM.aspx, (2023). Accessed: April 8, 2023.

22. Ohio Department of Transportation. Ohio Department of Transportation transportation asset management plan. https://www.transportation.ohio.gov/wps/wcm/connect/gov/c0cc661c-c457-4c83-aa31-4f2297d7aac4/2022+ODOT+TAMP.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_ M1HGGIK0N0JO00QO9DDDDM3000-c0cc661c-c457-4c83-aa31-4f2297d7aac4-opbE7hE, (2022). Accessed: April 8, 2023.

23. Hawaii Department of Transportation. Statewide transportation asset management plan. https://hidot.hawaii.gov/highways/files/2019/06/HDOT_TAMP_Final_ June2019.pdf, (2019). Accessed: April 8, 2023.

24. Oklahoma Department of Transportation. Transportation asset management plan 2019-2028. https://oklahoma.gov/content/dam/ok/en/odot/programs-and-projects/transportation-programs/ODOT TAMP 20190829.pdf, (2019). Accessed: April 8, 2023.

25. Idaho Transportation Department. Transportation asset management plan 2019-2023. https://itd.idaho.gov/wp-content/uploads/2019/06/ITD_TAMP.pdf, (2022). Accessed: April 8, 2023.

26. Oregon Department of Transportation. Transportation asset management plan. https://www.oregon.gov/odot/STIP/Documents/2022-Oregon-TAMP.pdf, (2022). Accessed: April 8, 2023.

27. Illinois Department of Transportation. IDOT: Group TAM plan for participating tier II agencies. https://idot.illinois.gov/content/dam/soi/en/web/idot/documents/transportation-system/reports/opp/transit/idot-2022-tamp-fhwa-certified-01-24-23.pdf, (2023). Accessed: April 11, 2024.

28. Pennsylvania Department of Transportation. Transportation asset management plan. https://www.penndot.pa.gov/ProjectAndPrograms/Asset-Management/Documents/PennDOT-TAMP.pdf, (2019). Accessed: April 8, 2023.

29. Indiana Department of Transportation. Transportation asset management plan. https://www.in.gov/indot/files/2022-TAMP.pdf, (2022). Accessed: April 8, 2023.

30. Rhode Island Department of Transportation. RIDOT transportation asset management plan. http://www.dot.ri.gov/documents/RhodeWorks/RIDOT_TAMP_2022.pdf, (2022). Accessed: April 11, 2024.

31. Iowa Department of Transportation. Transportation asset management plan 2023- 2032. https://iowadot.gov/systems_planning/fpmam/IowaDOT-TAMP-2023.pdf, (2023). Accessed: April 8, 2023.

32. South Carolina Department of Transportation. The strategic 10-year asset management plan. https://www.scdot.org/performance/pdf/reports/STAMP.pdf, (2022). Accessed: April 8, 2023.

33. Kansas Department of Transportation. Transportation asset management plan. https://www.ksdot.gov/Assets/wwwksdotorg/bureaus/burTransPlan/pubtrans/pdf/KDOT_TAMP_Final_062819.pdf, (2019). Accessed: April 8, 2023.

34. South Dakota Department of Transportation. Transportation asset management plan. https://dot.sd.gov/media/documents/DOT-TAMPlan.pdf, (2022). Accessed: April 8, 2023.

35. Kentucky Transportation Cabinet. Transportation asset management plan. https://datamart.kytc.ky.gov/DM_docs/048_kentuckytc.pdf, (2019). Accessed: April 11, 2024.

36. Tennessee Department of Transportation. Tennessee Department of Transportation transportation asset management plan. https://www.tn.gov/content/dam/tn/tdot/maintenance/asset-management-office-/tamp/2019.1.0 TAMP Report.Revised.8.26.2019.pdf.Revised.8.26.2019.pdf, (2019). Accessed: April 8, 2023.

37. Louisiana Department of Transportation and Development. Louisiana Department of Transportation and development transportation asset management plan 2018. http://www.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Data_Collection/Asset Management/LADOTD TAMP 2018 Version.pdf, (2018). Accessed: April 8, 2023.

38. Texas Department of Transportation. Texas Department of Transportation transportation asset management plan. https://ftp.dot.state.tx.us/pub/txdot-info/brg/transportation-asset-management-plan-2022.pdf, (2022). Accessed: April 8, 2023.

39. Maine Department of Transportation. MaineDOT transportation asset manage- ment plan. https://www.maine.gov/mdot/publications/docs/plansreports/ MaineDOT-Transportation-Asset-Management-Plan-final.pdf, (2019). Accessed: April 8, 2023.

40. Utah Department of Transportation. Utah Department of Transportation transportation as- set management plan. https://www.tam-portal.com/wp-content/uploads/sites/12/2022/05/025_utahdot.pdf, (2016). Accessed: April 8, 2023.

41. Maryland Department of Transportation. Maryland department of transportation asset management plan. https://www.mdot.maryland.gov/OPCP/MDOT_AMP_EF_2021_06_03.pdf, (2021). Accessed: April 8, 2023.

42. Vermont Agency of Transportation. Vermont transportation asset management plan. https://vtrans.vermont.gov/sites/aot/files/planning/documents/2018 Final VTrans TAMP.pdf, (2018). Accessed: April 8, 2023.

43. Virginia Department of Transportation. Virginia transit asset management plan. https://drpt.virginia.gov/wp-content/uploads/2023/07/tam-plan-2022.pdf, (2022). Accessed: April 11, 2024.

44. Michigan Department of Transportation. Michigan transportation asset managementplan. https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Planning/Asset-Management/TAMP-Jul-2022.pdf?rev=abf6d1b343aa4903860cf4a9d968dc41&hash=D997850D0860EC58FE7AE988A73FC3D0, (2022). Accessed: April 8, 2023.

45. Washington State Department of Transportation. Washington State Department of Transportation transportation asset management plan, https://wsdot.wa.gov/sites/default/files/2021-10/Washington-State-DOT-Transportation-Asset-Management-Plan.pdf, (2022), Accessed: April 8, 2023.

46. Minnesota Department of Transportation. Minnesota transportation asset management plan. https://www.dot.state.mn.us/assetmanagement/pdf/tamp/tamp.pdf, (2019). Accessed: April 8, 2023.

47. West Virginia Department of Transportation. West Virginia Department of Transportation transportation asset management plan. https://transportation.wv.gov/highways/plans/Documents/Plans/2022-Final-TAMP.pdf, (2022). Accessed: April 11, 2024.

48. Mississippi Department of Transportation. Mississippi transportation asset management plan, https://mdot.ms.gov/documents/Planning/Transportation Asset Management //Transporation Asset Management Plan 2023.pdf, (2022). Accessed: April 11, 2024.

49. Wisconsin Department of Transportation. Wisconsin Department of Transportation transportation asset management plan 2023-2032. https://drive.google.com/file/d/1BcV66KvlSg664RxJbCdxsEII8clvpEFi/view, (2023). Accessed: April 11, 2024

50. Missouri Department of Transportation. MoDOT national highway system transportation asset management plan. https://www.modot.org/sites/default/files/documents/Final Approved TAMP_08272019_0_0.pdf, (2019). Accessed: April 8, 2023.

51. Wyoming Department of Transportation. Wyoming Department of Transportation transportation asset management plan. https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Transportation-Plans/TAMP_WYDOT SubmissionPublic_Final_2.pdf, (2018). Accessed: April 8, 2023.

52. Texas Transportation Institute. Asset management literature review and potential applications of simulation, optimization, and decision analysis techniques for right-of-way and transportation planning and programming. Technical report, Texas Transportation Institute, (2006).

53. California Department of Transportation. Construction materials management systems: Survey of state practice. https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/construction-materials-management-systems-survey-of-stat pdf, (2019). Accessed: April 8, 2023.

54. AASHTOWare Project. AASHTOWare project: Construction & materials. https://www.aashtowareproject.org/apr-cm, (2023). Accessed: April 17, 2023.

55. Alabama Department of Transportation. Construction and Materials Management System (CAMMS). https://www.dot.state.al.us/publications/Construction/CAMMS.html, (2024). Accessed: April 8, 2023.

56. Alaska Department of Transportation and Public Facilities. AASHTOWare. https://dot.alaska.gov/aashtoware/, (2023). Accessed: April 9, 2023.

57. Colorado Department of Transportation. Documentation for SiteManager. https://www.codot.gov/business/designsupport/materials-and-geotechnical/manuals/2024-field-materials-manual/intro-docs/03-documentation-for-smm_ lims-24, (July 2023). Accessed: April 10, 2024.

58. Connecticut Department of Transportation. Personal communication. (August 2023).

59. Florida Department of Transportation. Appendix B. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/materials/structural/meetings/fdot-ccf/2014/appendixb.pdf?sfvrsn=87798f2_0, (2014). Accessed: May 4, 2023.

60. Georgia Department of Transportation. SiteManager. https://www.dot.ga.gov/GDOT/Pages/SiteManager.aspx. (2023). Accessed: April 11, 2024.

61. ExeVision. Case studies. https://www.exevision.com/case-studies, (2024). Accessed: April 11, 2024.

62. US Department of Transportation Federal Highway Administration. e-Commerce peer-to-peer summary report, Ohio DOT and Iowa DOT. https://www.fhwa.dot.gov/construction/econstruction/peer_exchange/ia_oh.pdf. (2024). Accessed: April 10, 2024.

63. State of Kansas.Department of Transportation: Notice to consulting firms. https://sos.ks.gov/publications/Register/Volume-41/Issues/Issue-23/06-09-22-50195.html, (2022).

64. AASHTOWare. AASHTOWare Project 4.2 Release. https://www.aashtoware.org/story/aashtoware-project-4-2-release/, (2020).

65. Headlight. How LADOTD is driving productivity. https://www.headlight.com/projects/dot/how-ladotd-is-driving-productivity/, (2023). Accessed: May 4, 2023.

66. Maine Department of Transportation. Personal communication. (June 2023).

67. Maryland Department of Transportation. MMS Laboratory Information Management Sys- tem (LIMS). https://roads.maryland.gov/OMT/04MQR-LIMS.pdf. (2024). Accessed: April 10, 2024.

68. Michigan Department of Transportation. Construction wiki. https://mdotwiki.state.mi.us/construction/index.php/Main_Page. (2023). Accessed: May 4, 2023.

69. AASHTO. Implementing AASHTOWare Project Construction and Materials with Missouri DOT. https://www.aashtoware.org/story/ implementing-aashtoware-project-construction-materials-with-missouri-dot/, (2019). Accessed: April 9, 2023.

70. Montana Department of Transportation. AWPR updates. https://www.mdt.mt.gov/other/webdata/external/css/aashtoware-cm/AWPR-Updates.PDF. (2023). Accessed: May 4, 2023.

71. Nebraska Department of Transportation. Transportation asset management. https://dot.nebraska.gov/media/gqnluggb/2018-iheep-asset-management-focus-group.pdf. (2018). Accessed: April 10, 2024.

72. US Department of Transportation Federal Highway Administration. e-Commerce Peer-to-Peer Exchange, Nevada DOT and Oregon DOT. https://www.fhwa.dot.gov/construction/econstruction/peer_exchange/nv_or.pdf. (2018). Accessed: April 10, 2024.

73. New Jersey Department of Transportation. AASHTOWare. https://www.state.nj.us/transportation/business/aashtoware/. (2023). Accessed: April 11, 2024.

74. New York State Department of Transportation. Section index. https://www.dot.ny.gov/main/business-center/trns-port/section-index. (2023). Accessed: April 11, 2024.

75. Ohio Department of Transportation. AWP construction materials, https://www.transportation.ohio.gov/working/construction/awp-construction-materials/home. (2023). Accessed: May 4, 2023.

76. Oklahoma Department of Transportation. AASHTOWare project page. https://oklahoma.gov/odot/business-center/construction-programs/aashtoware-project-web-application.html, (2024). Accessed: April 11, 2024.

77. Oregon Department of Transportation. AASHTOWare construction. https://www.oregon.gov/odot/Construction/Pages/AW-Construction.aspx, (2024). Accessed: April 11, 2024.

78. US Department of Transportation Federal Highway Administration. e-Commerce Peer-to- Peer Exchange, Pennsylvania DOT and Alabama DOT. https://www.fhwa.dot.gov/construction/construction/peer_exchange/pa_al.pdf. (2017). Accessed: April 10, 2024.

79. Rhode Island Department of Transportation. Personal communication. (October 2023).

80. South Carolina Department of Transportation. AASHTOWare project. https://www.scdot.org/business/aashtowareproject.aspx, (2023). Accessed: May 4, 2023.

81. Tennessee Department of Transportation. AASHTOWare project. https://www.tn.gov/tdot/tdot-construction-division/transportation-construction-division-resources/aashtoware-project.html, (2023). Accessed: April 11, 2024.

82. Aurigo. Utah DOT expected to save up to $100m using Aurigo masterworks cloud for capital planning and construction project management. https://www.aurigo.com/case-study/utah-department-of-transportation/, (2023). Accessed: May 19, 2023.

83. Vermont Agency of Transportation. Construction management system replacement project. https://vtrans.vermont.gov/highway/construct-material/e-construction/cms-replacement, (2024). Accessed: April 11, 2024.

84. US Department of Transportation federal Highway Administration. e-Commerce Peer-to- Peer Exchange, West Virginia DOT and Arkansas DOT. https://www.fhwa.dot.gov/construction/econstruction/peer_exchange/wv_ar.pdf. (2015). Accessed: April 10, 2024.

85. Wisconsin Department of Transportation. Materials. https://awpkb.dot.wi.gov/Content/materials/materials.htm. (2023). Accessed: May 4, 2023.

86. Aurigo. Construction project management software. https://www.aurigo.com/products/online-construction-project-mgmt-software/, (2024). Accessed: April 11, 2024.

87. ExeVision. e-Construction & project management. https://www.exevision.com, (2024). Accessed: April 11, 2024.

88. Headlight. Construction management software. https://www.headlight.com/, (2024). Accessed: April 11, 2024.

89. Thermo Fisher Scientific. Lab Information Management Systems (LIMS). https://www.thermofisher.com/us/en/home/digital-solutions/lab-informatics/lab-information-management-systems-lims.html, (2023). Accessed 2023. Accessed: April 8, 2023.

90. SynapticSci. Construction management software. https://www.synapticsci.com, (2024). Accessed: April 11, 2024.

91. Autoscribe Informatics. Laboratory Information Management Systems. https://www.autoscribeinformatics.com/, (2024). Accessed: April 11, 2024.

92. Quality Services International. Comprehensive LIMS. qsius.com, (2024). Accessed: April 11, 2024.

93. HaulHub. Haulhub technologies. www.haulhub.com, (2024). Accessed: April 11, 2024.

94. ATSER. State highway agencies. https://www.atser.com/state-highway-agencies/, (2023). Accessed: April 9, 2023.

This page left blank intentionally.

7.0 Appendix A: DOT Survey

LIMMS Survey - State DOTs

Start of Block: Introduction and Background Information

The following survey was provided to DOTs prior to interviews about their LIMMS usage.

Massachusetts Department of Transportation (MassDOT) is working with a research team in UMass Amherst to investigate the possibility of upgrading or procuring a new Laboratory Information and Material Management System (LIMMS) for its material testing laboratory. This online survey is addressed to state DOTs nationwide and examines what other state DOTs have done in this area. **It will take you about 15-20 minutes to complete the survey.**
--
By clicking "I agree" below, you indicate that you have read this introduction and agree to participate in this research study. Thank you in advance for your participation.

If you have questions, please contact:

Dr. Chengbo Ai, Assistant Professor
Department of Civil and Environmental Engineering
University of Massachusetts Amherst
chengbo.ai@umass.edu

- ○ I agree
- ○ I disagree

Page Break

I1 Your first and last name

_____

I2 Which transportation agency or authority are you working at?

_____

I3 Your role in your agency

_____

I4 Your email (we would like to share the results of this study with you)

_____

I5 Are you interested in talking with the research team as a follow-up interview?

- ○ Yes
- ○ No
- ○ Maybe

End of Block: Introduction and Background Information

Start of Block: System Description

SD1 What is the name and vendor (if any) of your agency's LIMMS?

_____

SD2 Have you performed any evaluation or analysis surrounding the choice of the vendor and the software that you would be willing to share? If so, which vendors were evaluated?

_____

_____

_____

_____

_____

SD3 Please describe your agency's LIMMS.

- ○ Customized software developed specifically for our agency
- ○ Commercial off-the-shelf (COTS) product.
- ○ COTS product customized for agency use
- ○ Other (Please describe)

_____

SD4 Why did your agency elect to develop a custom system rather than use an off-the-shelf version of a commercial product?

_____

_____

_____

_____

_____

SD5 Is the system web- or client-based?

_____

SD6 Does your agency use its LIMMS in conjunction with another system or tool? If yes, please describe the other system or tool and the interface with your LIMMS.

_____

_____

_____

_____

_____

SD7 If available, please provide links to documentation related to your agency's LIMMS. Please send any files not available online to chengbo.ai@umass.edu.

_____

_____

_____

_____

_____

End of Block: System Description

Start of Block: System Features

SF1 What features and functions are supported by your agency's LIMMS (even if your agency is not currently using them)? Please select all that apply.

	Yes	No	I don't know
Allows for exception tracking	○	○	○
Allows for review and management of producers	○	○	○
Allows for review and management of suppliers	○	○	○
Allows for review of mix designs	○	○	○
Certifies technicians	○	○	○
Generates invoices	○	○	○
Generates notifications to external users	○	○	○
Generates notifications to internal users	○	○	○
Manages new product evaluation	○	○	○
Manages review and authorization of samples	○	○	○
Manages specifications and test methods	○	○	○
Manages business partners	○	○	○
Manages testing workflows	○	○	○
Monitors instrument calibration and maintenance	○	○	○

	Yes	No	I don't know
Processes payments	○	○	○
Produces reporting	○	○	○
Provides access to external users	○	○	○
Provides 2FA or other advanced security features	○	○	○
Support mobile devices (e.g., RFID reader)	○	○	○

Page Break

SF2 Please describe other features and functions supported by your agency's LIMMS that do not appear in the list above.

_____

_____

_____

_____

_____

SF3 Please describe other features that are on your wishlist.

_____

_____

_____

_____

_____

End of Block: System Features

Start of Block: System Implementation

SI1 When did your agency implement its LIMMS?

_____

SI2 How long did it take to implement the system?

- ○ Less than 6 months
- ○ 6 months to less than 1 year
- ○ 1 year to less than 2 years
- ○ 2 years to less than 3 years
- ○ 3 years or more
- ○ Other (please describe)

SI3 What was the total cost to implement the system?

_____

SI4 What are the ongoing annual maintenance costs for the system?

_____

SI5 How often does your agency update the system?

_____

SI6 Who is responsible for system updates?

_____

Page Break

SI7 Has your agency experienced any challenges when developing and implementing system updates?

	Yes	No	I don't know
Incompatibity with other software	○	○	○
No backward compatibility	○	○	○
Upgrade fee is too high	○	○	○
Security concerns	○	○	○
Interruption of existing operations	○	○	○
Other (Please specify in the next question	○	○	○

SI8 Please describe the details of the challenges other than what are listed above.

_____

_____

_____

_____

_____

End of Block: System Implementation

Start of Block: Project Delivery Program Size

PD1 Please indicate the number of users with access to your agency's LIMMS.

- ○ Internal Users _____
- ○ External Users _____
- ○ Other Users (Please specify)

_____

PD2 What is the approximate number of construction projects your agency complete in a year?

_____

PD3 What is the approximate dollar value of construction projects your agency complete in a year?

_____

End of Block: Project Delivery Program Size

Start of Block: System Assessment

SA1 Please indicate your agency's level of satisfaction with each system characteristic listed below using the rating scale of from not at all satisfied to extremely satisfied.

	Extremely unsatisfied	Unsatisfied	Neither unsatisfied nor satisfied	Satisfied	Extremely satisfied	I don't know
Ease of use	○	○	○	○	○	○
Flexibility	○	○	○	○	○	○
Reliability	○	○	○	○	○	○
Security	○	○	○	○	○	○
Functionality	○	○	○	○	○	○
Overall satisfaction	○	○	○	○	○	○

SA2 Please describe the strengths of your agency's LIMMS.

_____

_____

_____

_____

_____

SA3 Please describe any challenges your agency has experienced using the LIMMS.

_____

_____

_____

_____

_____

SA4 Does your agency have any plans to transition to another LIMMS? If yes, please describe these plans.

_____

_____

_____

_____

_____

End of Block: System Assessment

Start of Block: Wrap-up

WU1 What recommendations do you have for an agency preparing to implement a new LIMMS?

_____

_____

_____

_____

_____

WU2 Please use this space to provide any comments or additional information about your previous responses.

_____

_____

_____

_____

_____

End of Block: Wrap-up