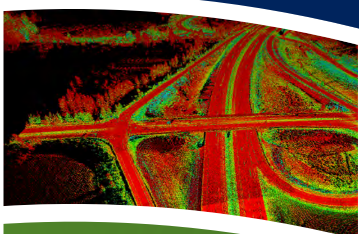
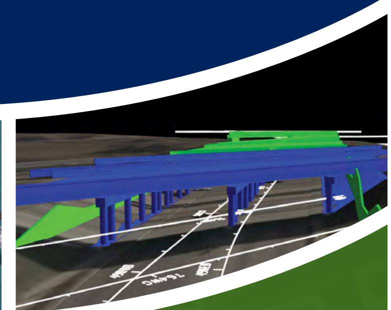
Guide for

Efficient Geospatial Data Acquisition using LiDAR Surveying Technology

Spring 2016





U.S. Department of Transportation
Federal Highway Administration

3D Engineered Models:
Schedule, Cost, and Post-Construction

*An **Every Day Counts** Initiative*

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Introduction

State transportation agencies (STAs) rely on federal and state funding to maintain and operate the transportation system within each state. The use of federal funds for transportation projects is regulated by the laws established by Congress. The Moving Ahead for Progress in the 21st Century (MAP-21) transportation bill introduced new programmatic performance measures with which the STAs must comply to use federal funds. MAP-21 has two major components: performance measures (i.e. data about the use, condition, and impact of the transportation system) and performance-based funding (i.e. performance measures to assist in prioritizing and selecting projects for funding), thus focusing on promoting transparency and accountability in the spending of public funds. Figure 1 summarizes the performance-based funding process. In order to comply with these new rules, STAs are relying on implementing innovative new processes and technology for managing roadway assets; LiDAR[1] surveys are one of these key enabling technologies.

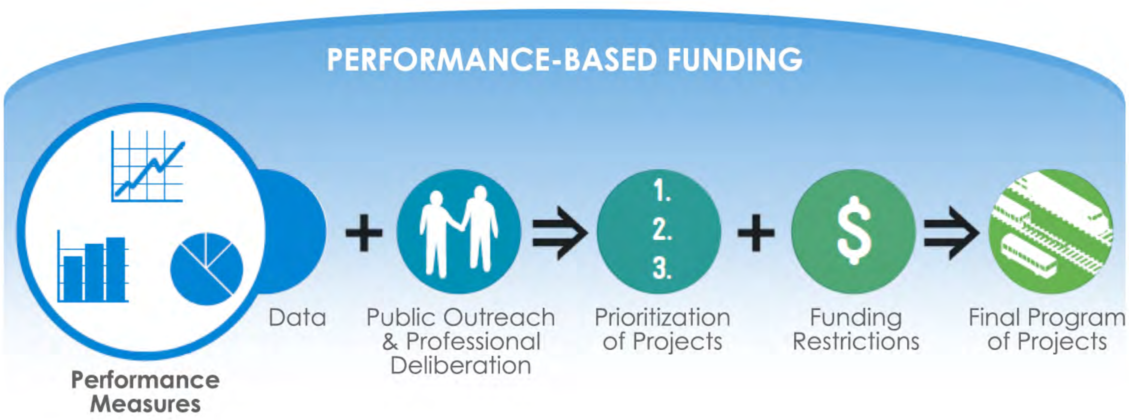


Figure 1: Illustration of Performance-Based Funding[2]

1 Light Detection And Ranging

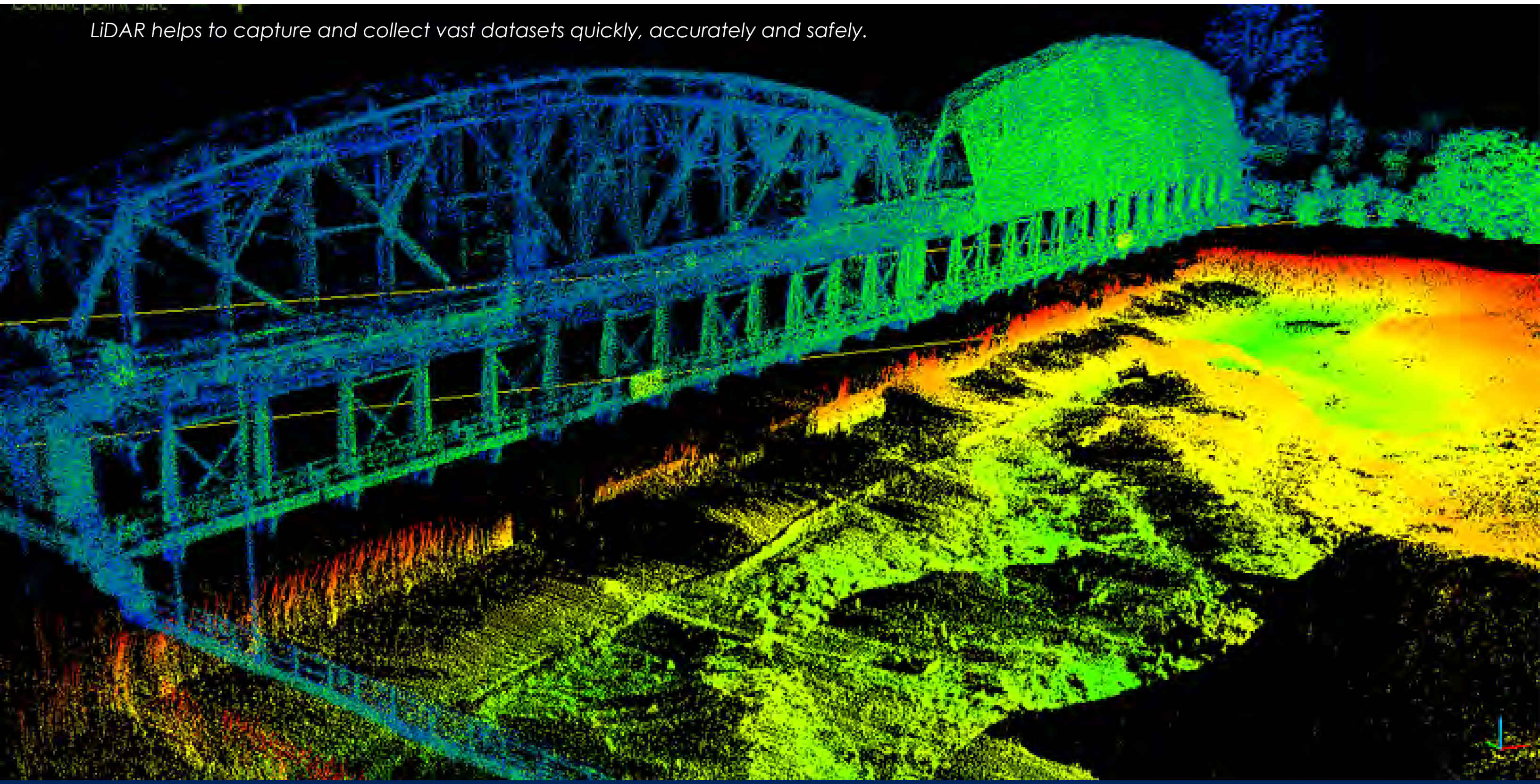
2 http://www.cmap.illinois.gov/about/updates/-/asset_publisher/UIMfSLnFfMB6/content/map-21-performance-measures-and-performance-based-funding. Accessed February 12, 2016

LiDAR surveys comprise an ever-evolving set of technologies that allow for a rapid, yet very accurate, collection of roadway asset data through a single effort which, when specified, integrated, and used correctly, can result in efficient workflows for agencies. While STAs may already be collecting data for specific purposes, these efforts are often duplicated within various agency disciplines using a variety of collection methods and standards. LiDAR surveys help consolidate resources, thus maximizing funding and enhancing the accuracy and integration of information. Additionally, some traditional survey practices could expose staff to unsafe conditions and create unnecessary traffic delays for the traveling public. Thanks to LiDAR, agencies across the country are beginning to conduct a variety of activities across disciplines that can be completed more rapidly and in a much safer and collaborative environment.

While the process for implementing LiDAR surveys will depend on a number of factors — most notably the agency's current pre-construction, post-construction, asset inventory practices, process maturity, internal technical resources, and available funding — this guide draws the decision makers' attention to the key issues that must be addressed for the optimization of data collection for use in an enterprise digital data solution. These include developing information requirements for data collection and products to be delivered for specific purposes and disciplines within the agency, and implementing the data collection program itself.

Program Planning: Developing Information Requirements

Unified information requirements are the foundation of a LiDAR program. They represent what an agency needs to know (i.e., to collect) in order to support the work of its various disciplines. These disciplines, however, tend to work with different terminologies, domains, and applications. As a result, information requirements within the agency vary depending on who is going to use the information and how. LiDAR surveys provide a unique opportunity to consolidate resources through a single collection effort. In exchange, however, they require all agency disciplines to define a common set of information requirements (shown in Figure 2).



LiDAR helps to capture and collect vast datasets quickly, accurately and safely.

Sharing enterprise data can only be achieved if it meets the needs of all stakeholders and if it is easily accessible. LiDAR surveys are a key means of beginning to overcome this challenge. Therefore, before initiating the data collection process, all disciplines within any given agency must collaboratively develop a unified set of information requirements that will guide data collection so that it satisfies everyone's operational needs. Such a set will include, at minimum, products to support transportation planning, right-of-way acquisition, environmental assessments and historic preservation, 3D design for roadway and structures, construction workflows, traffic operations, signing and striping, highway safety, maintenance activities, and multi-modal operations.

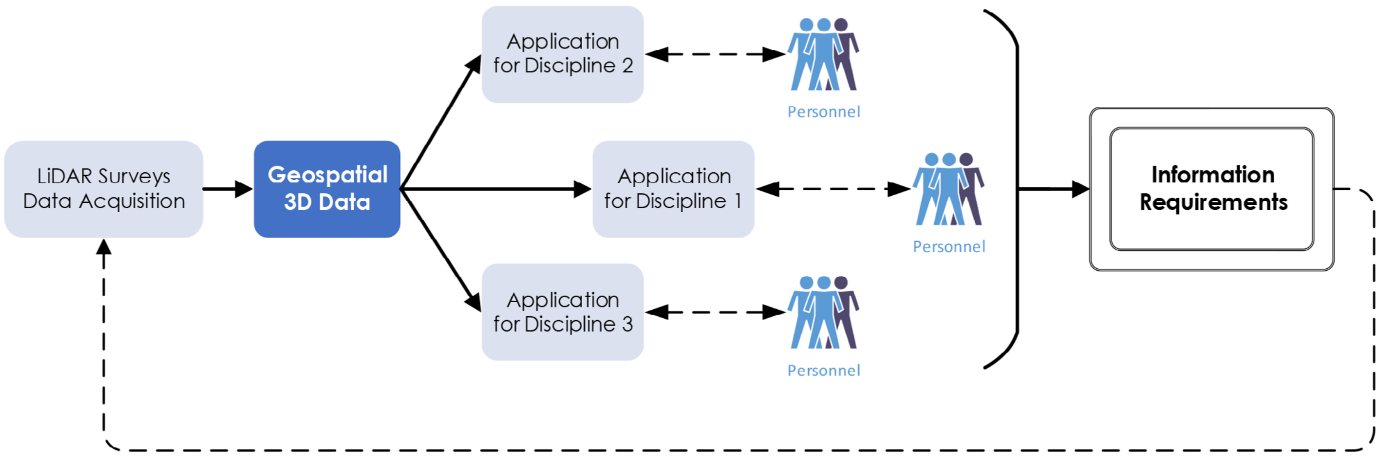


Figure 2: Development of Information Requirements for LiDAR

Data Acquisition Technology[3]

The technology to support data collection using LiDAR surveys is well established, but it continues to evolve to incorporate new advances in hardware and software. Today's data collection systems incorporate a variety of sensors based on three (3) major platforms, as shown in Figure 3. Availability of a GNSS network can be beneficial to an agency.

The purpose of the data determines the type of platform necessary for collecting it. Note that additional sensors may be added to the mobile platform for collecting pavement analysis, such as pavement profilers, and the Laser Crack Measurement System (LCMS™).[4]

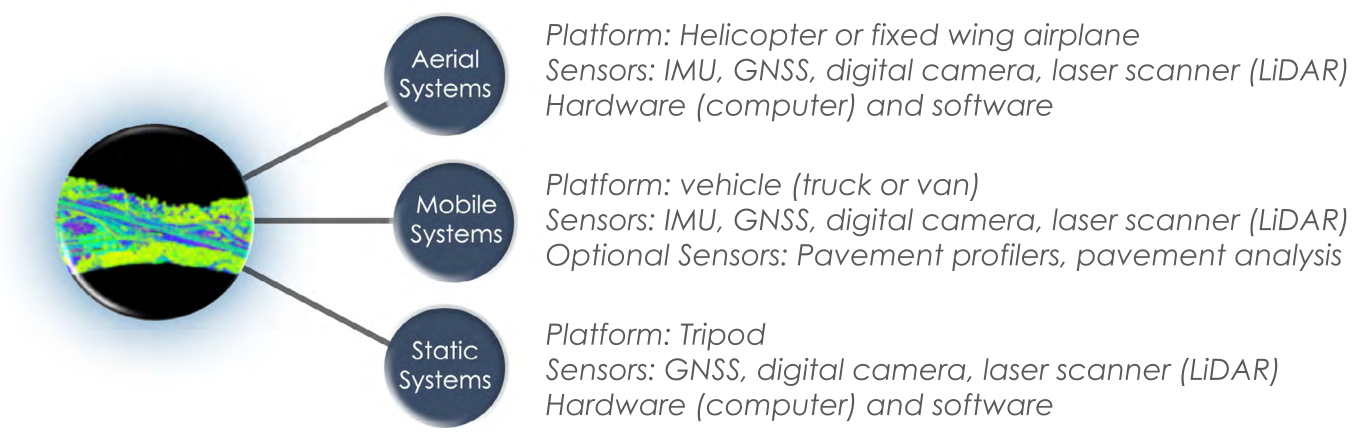


Figure 3: LiDAR Surveys Data Acquisition Platforms

3 Process of collecting data using remote sensing technologies, such as 3D surveys, photogrammetry, and satellites

4 Pavemetrics (www.pavementrics.com)

Data Requirements[5]

The resulting LiDAR survey product is a point cloud from which many derived by-products can be extracted and delivered to be consumed for various applications. A point cloud is a collection of data points in 3D space (x, y, z positioning), and it is defined by its characteristics, specifically: accuracy, density, and intensity. When setting data collection requirements, it is important to specify the desired characteristics and the level of post-processing to be completed on the final product(s).

What is LiDAR?

- **LiDAR, *Light Detection And Ranging*, is a remote sensing method that uses pulsed laser light to examine terrain and generate precise, three-dimensional (3D) information regarding surface shape and characteristics.**
- **LiDAR allows transportation agencies to capture and collect vast datasets more quickly, accurately and safely when compared to traditional survey methods.**

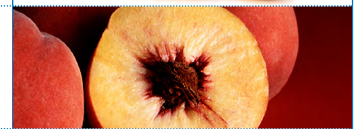
Accuracy, Density — Today, LiDAR surveying systems are categorized by asset/mapping grade and survey/engineering grade. The distinction is significant given its applicability, thus it is important for these requirements to be clearly communicated. Mapping grade accuracy is cheaper but only acceptable for applications requiring accuracies within a couple of feet, such as asset management and inventory mapping. On the contrary, survey/engineering grade accuracy is needed for applications requiring inch and sub-inch accuracy, such as engineering surveys or engineering design, and it is also much more expensive. In addition to accuracy, the desired data density should also be clearly specified. The need for the type of survey is driven by the information requirements set up front by the agency during the planning process. Greater accuracy generally results in more costs for data collection, processing, and storage. However, the data can be used beyond the intended purpose because it was collected at the highest possible accuracy level. Sensors continue to quickly advance to improve accuracy, thus performance-based requirements are highly recommended.

Table 1: Point Cloud Requirements

Accuracy	Network – Value that represents the uncertainty in the coordinates of the control points used for collecting the point cloud data with respect to a geodetic datum at 95% confidence. Absolute – The level of accuracy that can be obtained in a global coordinate system without reference to a geodetic datum. Local – Value that represents the uncertainty in the coordinates of the points in the point clouds relative to each other at 95% confidence level.
Density of Resolution	The attribute that describes the number of points per unit area. It can also be expressed as the average distance between points in a point cloud (e.g., 2-ft spacing).

5 This section is based on the recommendations of NCHRP Report 748 *Guidelines for the Use of Mobile LiDAR in Transportation Applications*. For more detailed requirements, please refer to NCHRP Report 748.

Table 2: Vertical Accuracies of LiDAR Data Acquisition Methods[6]

Method	Network Accuracy (RMS)	
Fixed Wing Aerial LiDAR/Photogrammetry	3" - 6"	
Low Altitude Helicopter LiDAR/Photogrammetry	1" - 2"	
Mobile LiDAR	½" - 1"	
Tripod-Mounted Static LiDAR	¼" - ½"	

Post-Processing — This is the process for making a point cloud consumable by other applications. It includes steps to extract data for a variety of applications (shown in Figure 4).

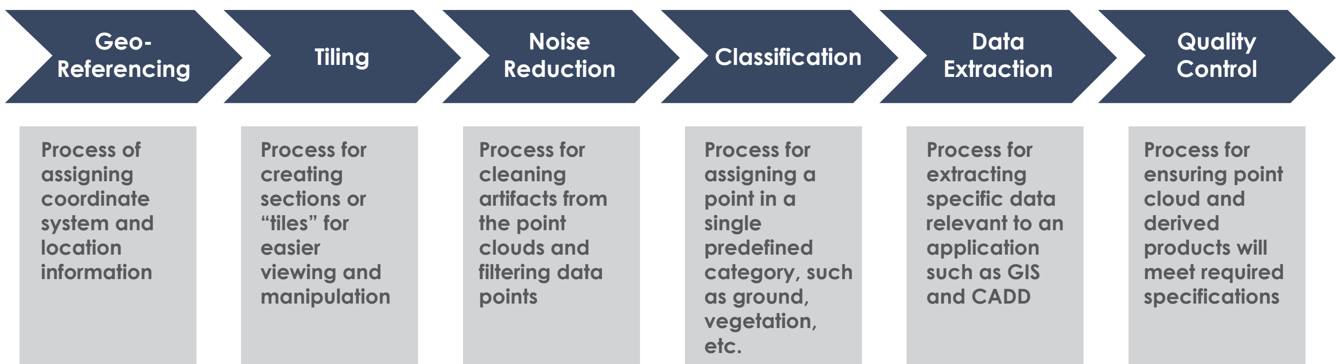


Figure 4: Basic Workflow for Post-Processing Point Clouds

Derived Product Requirements

Derived Products — Each application within a transportation agency has specific requirements in terms of accuracy and product types necessary to perform a function. Typical products extracted from a point cloud include features and metadata for databases (e.g., GIS, LRS, asset inventory) and CADD data (e.g., 3D models)[7], and if the 3D data acquisition system is equipped with a camera, additional products may include media files (e.g., imagery and videos). Figure 5 represents a sample of the types of products derived from a geospatial 3D survey and some of the applications in a transportation agency.

Data Dictionaries — A data dictionary consolidates all the requirements necessary to develop an adequate asset inventory. It details the assets to be collected, the features to be recorded for each particular asset, and the descriptors or identifiers to be used when recording each specific feature. Assets to be collected can be divided into two major groups: longitudinal (pavement, shoulders, guardrail) and discrete assets (bridges, sign structures, traffic signals). Then, for each asset, four different groups of features can be collected. These include characterization (ID number, subtype), location (route,

6 FHWA EDC-3 3D Engineered Models: Schedule, Cost and Post-Construction Workshop Materials
Image credits: Wikimedia Commons; Table credit: Wisconsin DOT

7 GIS – Geographic Information Systems, LRS – Linear Referencing Systems, CADD – Computer Aided Drafting & Design

coordinates[8]), geometry (width, height), and condition. Lastly, each feature can be recorded according to a specific descriptor, which includes a specific data type (e.g., number, text), data format (e.g., 3 digits, 6 digits, 10 characters), unit of measure (e.g., mile, point, feet, meter), and range of values (e.g., negative and positive, left and right).

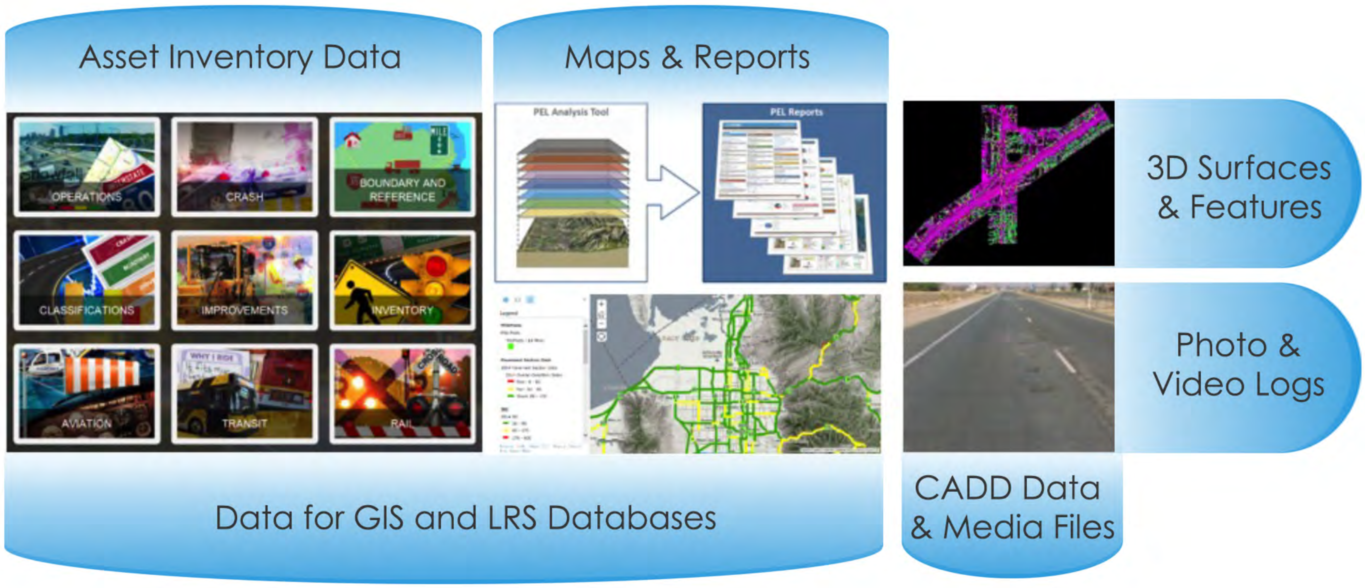


Figure 5: Typical Data Derived from 3D Survey Data Acquisition Systems and Examples of Applications[9]

Data Formats, Storage, Accessibility, and Archiving — For data to be shared by many systems and applications, the agency must require that data products be delivered in compatible, industry-standard file formats. Table 3 provides some examples. In addition, a thorough data management plan must be developed. Once the data is collected, it must be stored either at the agency or externally via enterprise data storage or a hosted service in such a way that it is easily accessible to the data consumers. A plan to back up and archive data should also be developed.

Table 3: Sample Data Formats by Type of Data Product

Data Product	LiDAR Point Cloud	Images	Video	CADD Data	GIS Data	Database
Sample Data Formats	LASer File Format Exchange (LAS), LAZ[10], or ASTM E57	Geographic Tagged Image File Format (GeoTIFF) or System Compatible File Format	Audio Video Interleave (avi), MPEG-4 Video File (mp4), Windows Media File (wmv), or System Compatible File Format	Digital Terrain Models (dtm, tin) Drawings (dgn, dwg) Digital Elevation Models (DEM)	Geodatabase Shape File (shp) or System Compatible File Format Digital Elevation Models (DEM)	Comma Separated Value (csv) or System Compatible File Format

8 The agency will need to define the geodetic information (coordinate system, geodetic datum, etc.) with which they want to work.

9 Image credit: Iowa DOT, Utah DOT, Caltrans, Missouri DOT, and FHWA.

10 Compressed version of LAS (typically 10-20%) without data loss. (NCHRP Report 748 Guidelines for the Use of Mobile LiDAR in Transportation Applications)

Data Management and Integration

Data management and integration is a much larger task than acquiring the data, and it requires a comprehensive enterprise data governance policy and strategic data integration plan. The agency solution to manage, integrate, and disseminate data relies on information systems infrastructure and technical support for the data to be accessible and to be of most value. A representation of data flow from data collection to business decision is shown in Figure 6.

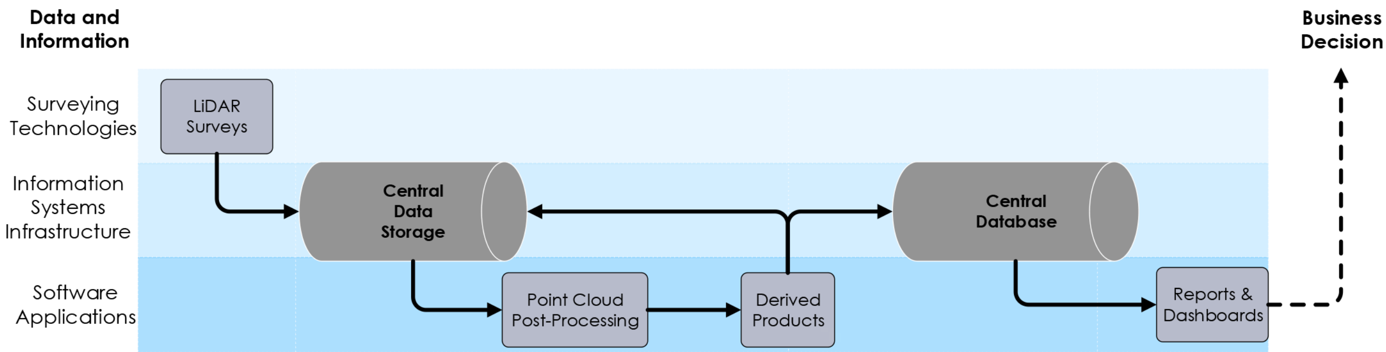


Figure 6: Data Flow and Evolution from LiDAR Surveys to Business Decision

Program Implementation: Enterprise LiDAR Surveys Data Acquisition

Developing a Business Plan

Having a clear business plan for collecting and using geospatial 3D data is paramount for a successful enterprise solution. At a minimum, a business plan should include a strategy to bring the organization from current state to the desired solution, including setting the organization's vision and goals, identifying priorities and resources, establishing milestones for specific tasks in the plan, and defining a timeline for accomplishing the overall goals. A thorough assessment of the agency's processes and maturity of infrastructure and technology expertise should be conducted prior to developing the agency strategy.

Defining an Enterprise Data Governance Program

The purpose of an enterprise LiDAR data acquisition program is to leverage data from collection through integration and dissemination. In order to accomplish this task effectively, it is imperative to establish an enterprise data governance plan. This document does not provide guidance on establishing a data governance program; that topic will be covered in a separate document titled Guide to Efficient Geospatial 3D Data Integration.

Updating Agency Survey Manual and Specifications

A survey manual and specifications that outline modern practices in geomatics are both key components in establishing a LiDAR survey data acquisition program. The survey manual and specifications are the foundation for establishing the specific protocol for data collection, including modern surveying techniques, desired products and related characteristics (such as accuracy, density, and intensity), quality control (QC) and assurance (QA) procedures, and acceptance protocol. In addition, these specifications need to be written in such a way that the guidance itself becomes a living document that can evolve along with the emerging technology and practices. Thus, establishing performance-based methods is the best approach for these specifications. The responsibility to update or set up a survey manual and specifications lies with the geomatics and surveying professionals, but it requires input from all stakeholders.

Establishing Data QC and QA Procedures

The quality of data captured by a LiDAR survey will largely determine the quality of the business decisions made from it. Thus, as collection takes place, the data should be subject to thorough QA. However, given the large amount of data at hand (likely in the order of tens of terabytes), QA cannot only occur at the end of the data collection exercise — redundancy of checks in the QA process is paramount. Therefore, an agency should not only designate a competent team to review and ensure that the deliverables meet the requirements, but also consider securing the services of a qualified and independent team to verify that the work product is compliant with the specifications.

The same considerations apply if an agency decides to outsource its LiDAR survey data acquisition program. In such a case, however, the contractor should also be required to provide a QC plan that explains how accurate and high-quality data will be achieved and maintained and how any deficiencies will be remedied. To further encourage delivery of high-quality data, incentive and disincentive clauses can be considered in the contract letting process based on independent checks conducted at designated road sections.[11]

Launching a LiDAR Survey Program: Agencies versus Professional Services [12]

Agencies can either establish a LiDAR survey program internally or procure professional services. The cost of agency ownership includes the cost of equipment, training, post-processing software, and any associated maintenance and upgrades. Alternatively, procuring professional services only includes the cost for data acquisition and required products. A third option would be to consider a hybrid approach, in which the data collection is procured while the post-processing is performed internally with agency resources. The data acquisition workflow is shown in Figure 7.

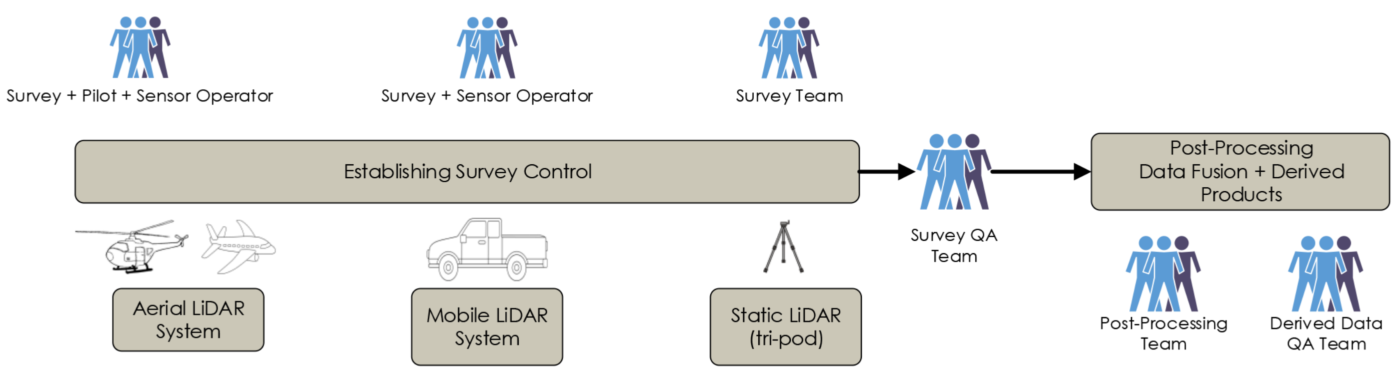


Figure 7: LiDAR Survey Data Acquisition Workflow

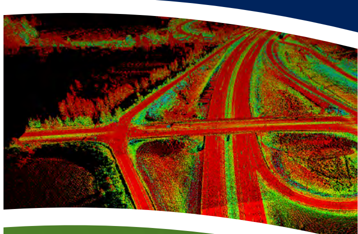
11 Each check would involve a comparison between values measured by the agency and values measured by the contractor for a particular feature. The overall potential for incentives/disincentives should be around 10% of the total contract value.

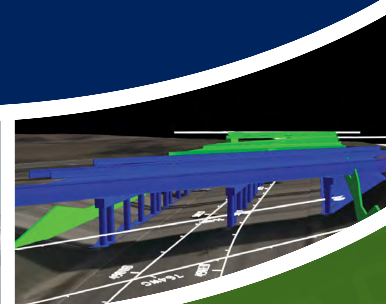
12 More detailed information may be obtained from NCHRP Report 748

Consideration for Future Use of Geospatial 3D Data

Effective use of geospatial 3D data is in its infancy, but offers potential beyond our imagination. Platforms will continue to evolve, accuracies will continue to improve, and new software applications will emerge to accommodate current and future needs. While implementing an enterprise LiDAR survey data acquisition program is a large task to undertake, agencies can optimize their current data acquisition practices to grow and evolve to rely on geospatially accurate data to manage roadway assets throughout their life cycle.

Every Day Counts*, a state-based initiative of the Federal Highway Administration's Center for Accelerating Innovation, works with state, local and private sector partners to encourage the adoption of proven technologies and innovations to shorten and enhance project delivery.*





U.S. Department of Transportation

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For additional information about this EDC Initiative, please contact:

Christopher Schneider
Construction Management Engineer
Office of Infrastructure (HIAP-30) — FHWA
Phone: (202) 493-0551
Email: christopher.schneider@dot.gov

R. David Unkefer, P.E.
Construction & Project Management Engineer
FHWA Resource Center - Atlanta
Phone: (404) 562-3669
Email: david.unkefer@dot.gov

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