

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

PROGRAM CASE STUDY



This case study highlights LiDAR technology as a surveying tool to support current transportation agency business applications and the true value of combining 3D survey data from multiple sources, such as traditional surveying equipment (i.e., robotic total stations, Global Navigation Satellite Systems or GNSS, photogrammetry, and LiDAR sensors) by the California and the North Carolina Departments of Transportation. It is offered as a general aid for those considering starting similar programs or enhancing existing ones. It provides two examples of how state transportation agencies might expand the use of 3D engineered models.

Geomatics Workflows:

California and North Carolina Integrating Light Detection and Ranging (LiDAR) into Existing Surveying Practices

Providing a safer transportation network and moving people and goods efficiently while providing sustainable infrastructure solutions are some of the major tasks transportation agencies must accomplish as part of their everyday business. In addition, today's environment includes the added challenge of completing these tasks with limited resources, which has forced agencies to rely on innovative solutions and optimization of new technologies.

State transportation agencies (STAs) rely on geomatics¹ engineering technologies for collecting and sharing data across multiple disciplines. While the geomatics toolbox includes a variety of methods for collecting and sharing data, this case study specifically focuses on LiDAR technology. The use of LiDAR to collect data is becoming more widely adopted as the tool of choice among STAs due to an industry-led outreach and education movement over the last few years to make surveyors and engineers more comfortable with this new approach and type of data. In addition, the technology itself is becoming more cost-effective to implement and more accessible due to the availability of multiple service providers.

Caltrans: Organizational Overview

Caltrans is responsible for managing a roadway network of more than 50,000 lane miles of state highways and interstates and over 13,000 bridges. The agency also permits over 40 public-use airports and operates three of the five Amtrak intercity rail services nationally.

The agency has a total operating budget of \$10.5 billion. Caltrans has its headquarters in Sacramento and is divided into 12 operating districts across the state. The Project Delivery team situated within headquarters includes multiple divisions who together support the delivery of the annual construction program.

Caltrans' Land Surveys program provides technical support for the various disciplines within the project delivery team through the use of advanced surveying technology and establishes the geospatial foundation for California's transportation infrastructure. Land surveying offices exist in each district, with corporate and technical support from the Office of Land Surveys and the Office of Photogrammetry and Structure Preliminary Investigations in Sacramento. Surveying data collection is conducted at the district level to meet

¹ Geomatics is the science and technology of gathering, analyzing, interpreting, distributing, and using geospatial information, and encompasses 3D surveying and mapping, geographic information systems, and global navigational satellite systems. http://healthcybermap.org/HGeo/pg2_1.htm. Accessed February 4, 2016.

the engineering requirements for delivering the state transportation improvement program (STIP). Utilization of advanced surveying technology and innovative solutions are key components in Caltrans' surveying practices for meeting the department's mission to provide a safe, sustainable, integrated and efficient transportation system to enhance California's economy and livability.

Surveying Technology and Innovation Supporting Caltrans Business

Caltrans has been collecting 3D survey data with a variety of surveying equipment for over 20 years, and in the early 2000s, several static terrestrial LiDAR scanning (STLS) systems were added as new surveying tools. In 2008, Caltrans was introduced to the utilization of mobile terrestrial LiDAR scanning (MTLS) through consulting services, and in 2012, the first survey grade MTLS system was purchased and deployed for internal data acquisition. Caltrans invests, on average, \$2 million every year to support and maintain surveying technology and practices. Some of the benefits of LiDAR technology include increased safety and better data that can be used beyond the design phase of a project. However, the agency has not completed a formal cost-benefit analysis.

“Cost benefits from the use of advanced geomatics technologies are mostly anecdotal at this point, but our field survey crews are smaller today than they were 10 years ago. They are also more efficient and provide a better level of service and a more robust product.”

– Mark Turner, P.L.S. – Chief, Office of Land Surveys Caltrans

The decision to use a specific surveying technology depends on project requirements, safety and accessibility conditions, schedule, and funding. The surveying professionals are responsible for verifying the quality of the data and recording metadata to document coordinate systems, datum, and data collection sources. The Land Surveys program is a service provider for engineering data. Standard derived products include traditional computer aided design and drafting (CADD) data, such as 3D digital terrain model (DTM) depicting surfaces, points, features; geographic information systems (GIS) data for planning project staging; data for structure monitoring and analysis; and data to support the Legal Division for accident investigation and court purposes.

District 4 (San Francisco-Oakland-San Jose Bay Area) is one of the Caltrans districts leading the way as early adopters of LiDAR technology to support surveying operations. The survey staff in District 4 has developed processes to provide a proof of concept for enterprise adoption, but have also identified the following technical challenges: (1) disparate data quality from various sources, (2) uncertainty in geodetic characteristics and quality, (3) data integration, and (4) appropriate use of data from various sources.

Setting Specifications and Infrastructure to Support LiDAR Data Utilization

Setting specifications and infrastructure is the first step in trying to address the technical challenges previously mentioned. Caltrans had a contract with the University of California at Davis to perform a research project (Hiremagalur et. al., 2007)² to develop standards and specifications for LiDAR that the agency could use for large scale deployment of the technology for day-to-day surveying operations. The research project recommendations became the basis for the first set of specifications for stationary and mobile terrestrial LiDAR, which Caltrans adopted in 2011. The specifications for LiDAR surveys (both static and mobile) are detailed in Chapter 15 of the Caltrans Surveys Manual. Caltrans LiDAR specifications gained nationwide attention, and quickly became a reference guide for other agencies exploring the technology³. The LiDAR specifications address some of the identified challenges by providing guidance on what applications are appropriate for LiDAR data, and also set the standard procedures to ensure geodetic characteristics and quality. Figure 1 represents a summary of the specifications.

² Hiremagalur et al. (2007). Creating Standards and Specifications for the Use of Laser Scanning in Caltrans Projects.

³ Caltrans specifications may be obtained via the internet at http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/15_Surveys.pdf

Caltrans LiDAR Scanning Specifications



Figure 1: Summary of Caltrans LiDAR Specifications

District 4 survey staff has developed a process to collect data and produce derived products called “digital reality capture.” This process relies on a fusion of data from conventional surveys, STLS, and MTLs that are either available in-house or through consulting services. The process to extract data and create the derived products for the end-user are vendor agnostic. Thus, requiring the agency to have access to a variety of software packages and staff well-versed in the use of these tools. In the end, the data extraction provides a modular 3D environment containing vector, raster, and point cloud data to be used for every phase of the project from planning to construction. The process District 4 uses to extract features and create DTMs and other derived products is shown in Figure 2.

Data Sources: Conventional Survey + STLS + Survey Grade Control



Figure 2: Caltrans District 4 Process for DTM Creation⁴

Managing LiDAR data can also be a challenge in terms of storage and distribution, thus establishing an Information Technology (IT) infrastructure that will support the collection, post-processing and distribution is critical for successful utilization of the data. The survey operations in District 4 rely on a NetApp® server shown in Figure 3, which supports dedicated storage for raw and processed data. The storage volumes can be expanded or reduced without any adverse effect on the data, and the system has data redundancy to guard against data loss due to hard drive failure.

⁴ Images courtesy of Caltrans.

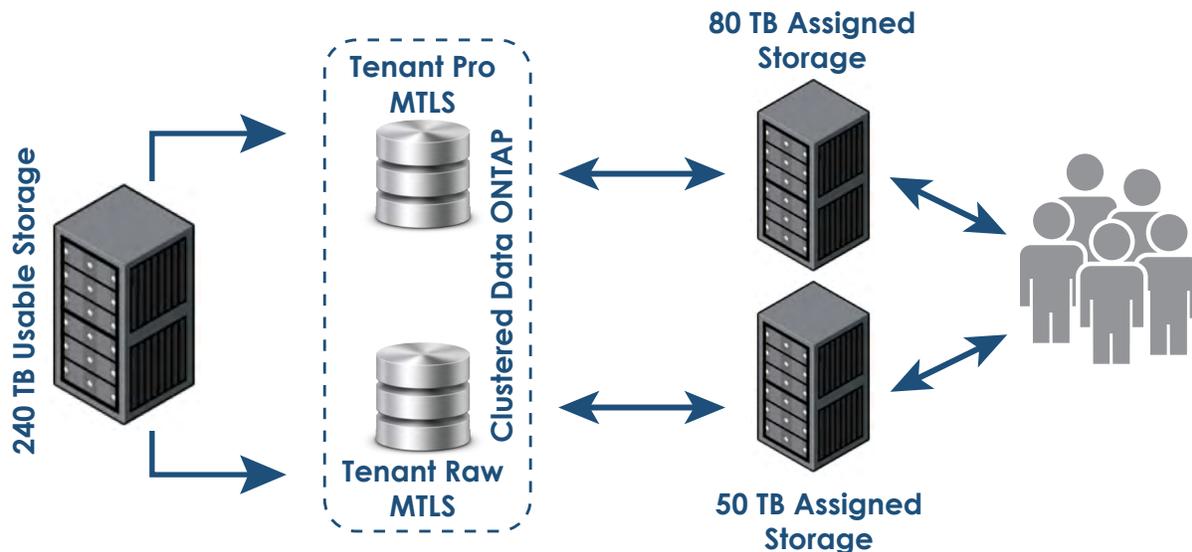


Figure 3: District 4 Server Configuration for LiDAR Storage

Caltrans will continue to work towards their goal of establishing an enterprise solution for core level geospatial data acquisition defined in the second round of Every Day Counts (EDC-2) Initiative. As a result, the agency has produced a set of recommendations, supported by the mission statement: Caltrans provides core transportation data, forming a foundation for internal collaboration that helps achieve its mission, vision and goals. The geospatial data acquisition strategic goals are defined in the Caltrans Land Surveys Strategic Direction, which was finalized in January 2015, and focuses on leading the creation, management, and visualization of geospatial data. In addition, a Caltrans Geospatial Governance Board has been established to review the recommendations and take possible action to an enterprise solution for core level geospatial data acquisition, with LiDAR being central to this framework.

“We need to change our culture to think about our data collection more strategically, looking beyond the immediate project needs, so we can benefit from the data throughout assets’ life-cycle.”

– Nelson Aguilar, PLS – District 4 Office Chief, Office of Field Surveys Services

Caltrans Division of Research, Innovation and Systems Information is working with District 4 and University of California at Davis to create specifications for system configuration, data structure, and database for metadata. In addition, the project will also develop a geospatial online system using a customized graphic user interface (GUI) that connects to Caltrans’ NetApp server to catalog data sets. The system will result in a web-based geospatial system that internal and external customers can use to search and access data sets. The proto-type system is on schedule to be rolled out by June-2016.

NCDOT: Organizational Overview⁵

The NCDOT is responsible for managing a state roadway network of nearly 190,000 lane miles (include county, state, and 1,300 lane miles of interstates), and over 18,000 bridges and drainage structures. The agency has a \$4.4 billion total operating budget, from which 60% is funded through state revenue. The agency’s highway program is delivered primarily by the Division of Highways (DOH), and the Division of Technical Services (DTS). While the DOH has always had both central and field-based functions, the DTS until the recent switch to optimize staff utilization in the division offices, had always provided services to support project delivery from the central office. However, both the Photogrammetry and the Location and Surveys units reside within the DTS as

⁵ Overview based on NCDOT 2015 annual report. http://www.ncdot.gov/download/performance/2015_NCDOT_AnnualReport_web.pdf

central functions, and together provide geomatics services for functions at the central office and the 14 field-based divisions delivering the construction program.

The Photogrammetry Unit provides aerial imagery and geospatial information products used for transportation planning, design, construction, and maintenance. Similarly, the Location and Surveys Unit provides topographic surveys and LiDAR products to support program delivery functions. These two units work closely together to deliver a solution that meets the needs of the agency while encouraging safety and cost-effectiveness.

NCDOT's Journey to Better Data for Achieving Agency Goals

NCDOT's vision is to use LiDAR surveys for data collection as a supplement to well established processes using a variety of technology, such as photogrammetry, and traditional topographic surveys. The agency vision for data collection and accessibility is to support a variety of engineering applications used for accomplishing goals of making their transportation network safer and more efficient, which is in line with the agency's performance-based measures to support accountability and transparency.

Establishing Standard Operating Procedures

The surveying and photogrammetry staff is responsible for providing digital data for project delivery, and this process is accomplished by combining data from different sources to develop 3D data models (i.e. digital elevation models or DEMs, DTMs, and 3D topographic features).

The standard process at NCDOT relies on photogrammetry to extract visible data in the 3D aerial model, while ground surveys concentrate on collecting obscured planimetrics, underground utilities, and property boundaries as well as the areas where greater accuracy is needed (i.e. pavement, hydrographic surveys). Photogrammetry uses statewide LiDAR (QL2⁶) whenever available. This process is shown in Figure 4. While this process is now a standard operating procedure, the process was first piloted in 2014 on transportation improvement project (TIP) U-4407 in Wayne County. NCDOT is now using this process on approximately 100 projects.

The survey staff supplements photogrammetric data models with traditional surveys, static, and/or mobile LiDAR depending on the needs of the project. The survey staff sets the control, and can collect and post-process the static LiDAR data in-house, or by professional services. Mobile LiDAR is only acquired through professional services, and it is used specifically for deriving pavement DTMs for widening and resurfacing projects while the photogrammetric DTM is used for calculating earthwork quantities. Examples of the derived products from ground surveys are shown in Figure 5.

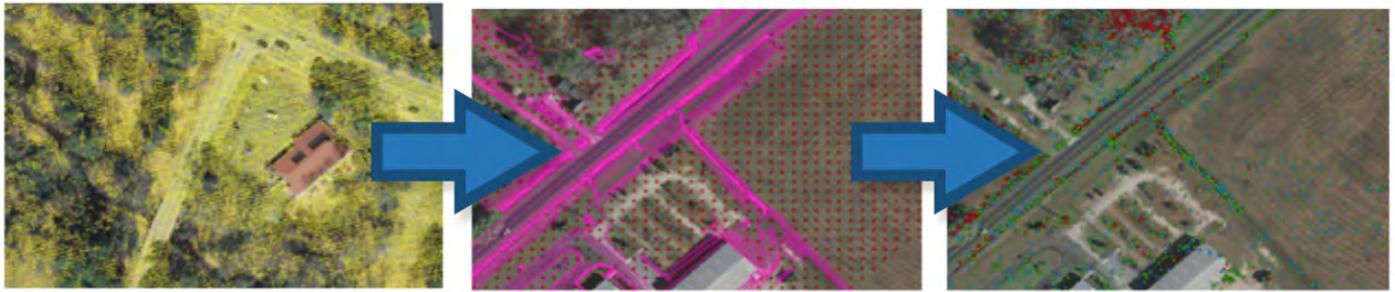
The data source for each project can be determined by level symbology in the CADD drawing. Each data source is assigned a set of levels or layers in the drawing. In essence, the NCDOT is optimizing the fusion of data sets from multiple sources to provide the best quality and most cost-effective product for roadway design.

In addition to delivering the traditional design products, the survey staff also delivers asset management data for structures, such as metadata of structure dimensions and clearance information, and sketches that are then used to populate the structures management database. The data is extracted using LiDAR post-processing software. The workflow for product delivery is shown in Figure 6.

"Fusion of data from various sources provides a way to create a product that everyone can use."

– Keith Johnston, PE, PLS – Photogrammetry Manager, Division of Technical Services

⁶ Quality Level 2: Statewide High Resolution LiDAR Data (Fundamental Vertical Accuracy or FVA of 0.59 ft. expressed at 95% confidence level. This data is available for approximately one-third of the state.



Data Source: 3D Cloud Point Aerial Imagery	Process: Add Breaklines and Mass Points Extract Topographic Features	Final Product: QL2 Bare Earth Point Cloud DTM (Breaklines/Mass Points) CADD Topographic Drawing
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Figure 4: NCDOT Process for Optimizing Quality Level 2 Aerial LiDAR



Data Source: Survey Control Conventional Topographic Surveys Mobile LiDAR Data Set Static LiDAR Data Set	Process: Post-Process Control Extract Topographic Features Create DTMs	Final Product: DTM (Geopak TIN) CADD Drawing (DGN)
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Figure 5: Example of LiDAR Derived Products⁷

Like Caltrans, NCDOT identified managing and storing data as primary challenges. In addition, NCDOT is struggling with the end-user hardware and software limitations. To start addressing some of these challenges, the agency has established a plan for managing aerial LiDAR, and until hardware and software can be upgraded, the data files will continued to be reduced so data to be consumable. NCDOT also recognizes that the utilization of LiDAR data from various sources can only be successful when having skilled and competent staff that understands not only the technology, but also the intended use of the data.

“Enterprise utilization of LiDAR data depends on people learning the added value it brings.”

– Charles Brown, PE, PLS – State Location & Surveys Engineer, Division of Technical Services

⁷ Images courtesy of NCDOT

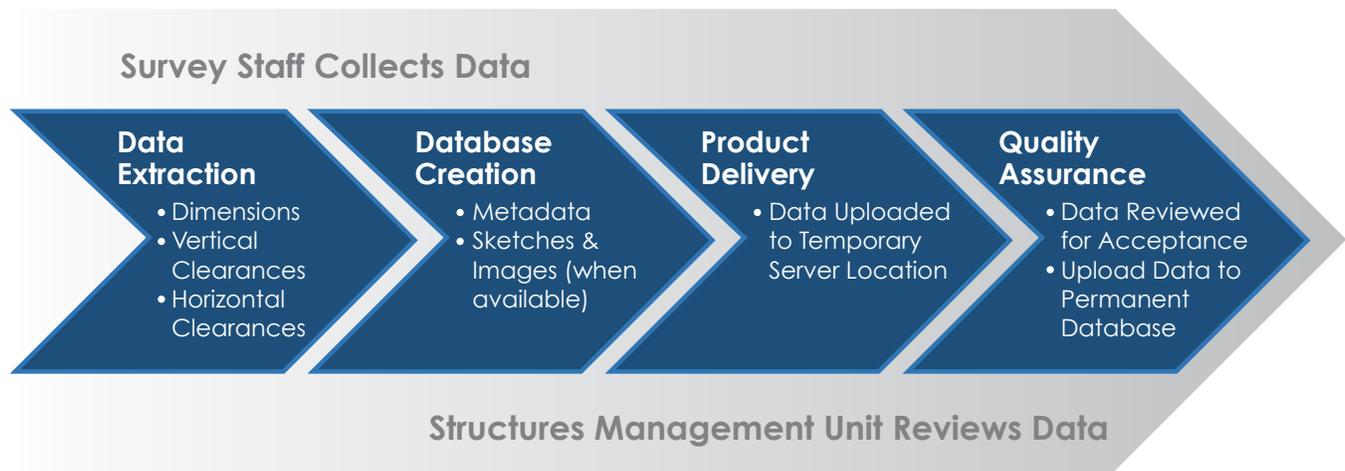


Figure 6: Workflow from Collection to Consumption for Structural Assets.

The Future of Geomatics

LiDAR surveys are yet another 3D technology that can be used to supplement existing processes and products. The technology offers great potential for data used across various disciplines, but the true value of LiDAR data sets is the ability to combine it with other 3D surveys. It is clear that storing, managing, and distributing the data are the next challenges to address for better utilization of this technology as an enterprise data source to manage transportation assets.

Note: The U.S. Government, the California Department of Transportation, and the North Carolina Department of Transportation do not endorse products or manufacturers. Trademarks and vendor/manufacturers' names appear in this report only because they are considered essential to the objective of the document.

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Every Day Counts (EDC), a State-based initiative of FHWA's Center for Accelerating Innovation, works with State, local and private sector partners to encourage the adoption of proven technologies and innovations aimed at shortening and enhancing project delivery.



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