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LiDAR for Geotechnical Applications

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13. Abstract
This research focused on the utilization of Light Detection and Ranging (LiDAR) technology within the Louisiana Department of Transportation and Development (DOTD) for various geotechnical applications. The study addressed several key practices, including site investigation and reconnaissance for drilling operations, geotechnical asset management inventory data collection, change detection for forensic evaluations and monitoring, and cross-section data collection for stability analysis. The primary objective of the research was to leverage LiDAR technology to enhance geotechnical infrastructure management within DOTD. The investigation involved a comprehensive analysis of available data within DOTD and other relevant Louisiana agencies. Additionally, the study explored the integration of LiDAR with other data sources and collection technologies, such as drones for local

scanning. The research findings contribute to the identification and implementation of LiDAR technology in geotechnical infrastructure, providing valuable insights into its efficacy and potential benefits. By harnessing LiDAR for site investigation and reconnaissance during drilling operations, the study aims to improve the accuracy and efficiency of data collection in challenging terrains. Further, the research explored the role of LiDAR in geotechnical asset management, emphasizing the importance of inventory data collection. Through change detection techniques, LiDAR proves to be a valuable tool for forensic evaluations and continuous monitoring of geotechnical assets, facilitating proactive maintenance and risk mitigation. The study also explores the application of LiDAR in cross-section data collection for stability analysis. By assessing terrain morphology and structural integrity, LiDAR contributes to a more thorough understanding of geotechnical conditions, enabling better-informed decision-making for infrastructure stability and resilience. In conclusion, the research underscores the potential of LiDAR implementation in geotechnical applications within DOTD, offering a sustainable and resilient approach to infrastructure management. The insights gained from this study have the potential to enhance DOTD's capabilities in site investigation, asset management, and stability analysis, ultimately contributing to the long-term sustainability of geotechnical assets.

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Abstract

This research focused on the utilization of Light Detection and Ranging (LiDAR) technology within the Louisiana Department of Transportation and Development (DOTD) for various geotechnical applications. The study addressed several key practices, including site investigation and reconnaissance for drilling operations, geotechnical asset management inventory data collection, change detection for forensic evaluations and monitoring, and cross-section data collection for stability analysis. The primary objective of the research was to leverage LiDAR technology to enhance geotechnical infrastructure management within DOTD. The investigation involved a comprehensive analysis of available data within DOTD and other relevant Louisiana agencies. Additionally, the study explored the integration of LiDAR with other data sources and collection technologies, such as drones for local scanning. The research findings contribute to the identification and implementation of LiDAR technology in geotechnical infrastructure, providing valuable insights into its efficacy and potential benefits. By harnessing LiDAR for site investigation and reconnaissance during drilling operations, the study aims to improve the accuracy and efficiency of data collection in challenging terrains. Further, the research explored the role of LiDAR in geotechnical asset management, emphasizing the importance of inventory data collection. Through change detection techniques, LiDAR proves to be a valuable tool for forensic evaluations and continuous monitoring of geotechnical assets, facilitating proactive maintenance and risk mitigation. The study also explores the application of LiDAR in cross-section data collection for stability analysis. By assessing terrain morphology and structural integrity, LiDAR contributes to a more thorough understanding of geotechnical conditions, enabling better-informed decision-making for infrastructure stability and resilience. In conclusion, the research underscores the potential of LiDAR implementation in geotechnical applications within DOTD, offering a sustainable and resilient approach to infrastructure management. The insights gained from this study have the potential to enhance DOTD's capabilities in site investigation, asset management, and stability analysis, ultimately contributing to the long-term sustainability of geotechnical assets.

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The researchers would like to acknowledge DOTD Section 30, including Stan Ard, Steve LeBlanc, Jeremy Penton and Dustin Smith, for their insight and help in collecting, interpreting, and analyzing drone and LiDAR data. Additional thanks goes to LTRC Technician Chris Mertz for his work throughout the research effort. DOTD Section 67 is also acknowledged for their assistance with the research.

Implementation Statement

This project connected the capabilities of existing LiDAR references with existing DOTD processes for utilization by the Department's Geotechnical Design section. LiDAR can be used in a variety of ways, and as the technology becomes more cost effective, it will become more prevalent in our daily work life.

Table of Contents

List of Tables

List of Figures

Introduction

As the bedrock of robust infrastructure development, geotechnical engineering constantly seeks innovative technologies to improve its methodologies for site investigation, asset management, and stability analysis. In this context, the emergence of Light Detection and Ranging (LiDAR) technology has catalyzed a paradigm shift, offering unprecedented capabilities in capturing high-resolution spatial data. This research endeavored to unlock the full potential of LiDAR within the Louisiana Department of Transportation and Development (DOTD), addressing critical geotechnical challenges and revolutionizing traditional practices.

The topography and geological diversity of Louisiana present intricate challenges for geotechnical engineers, demanding sophisticated tools to navigate and interpret complex terrains. LiDAR, with its ability to capture three-dimensional point clouds and provide detailed terrain models, has emerged as a transformative solution. This study strategically targeted key aspects of geotechnical engineering within DOTD, each contributing to a comprehensive understanding of LiDAR's role in optimizing infrastructure management.

LiDAR is a method of measuring distances by emitting thousands of laser beams and measuring their reflections from surrounding surfaces. The technology calculates distances based on reflection times and vectors from/to the laser to create a point cloud of spatially related points. Some projections are so dense that they can appear like a photo or image. Initially very expensive, LiDAR is becoming more common and affordable, and it is utilized for mapping, measuring, and creating digital twins. LiDAR data collection occurs from vehicles, drones, and/or fixed-wing airplanes. Louisiana DOTD has begun collecting LiDAR data on state highways, but access to the data has not been linked to geotechnical applications. LiDAR data can be used for many purposes, and though the primary reasons are likely not related to geotechnical concerns, the data can still be of benefit to DOTD's geotechnical groups.

The research focused on available data within DOTD and other Louisiana state agencies. Researchers investigated other data sources and collection technologies, such as drones, for local scanning. This project investigated the utilization of LiDAR within DOTD for geotechnical applications. Stan Ard, Survey Administrator, and his staff, including aircraft and GIS Specialists, are the lead data coordinators for DOTD LiDAR and were a valuable source of information.

The research focused on four objectives regarding LiDAR within DOTD for geotechnical applications:

1. **Site investigation and reconnaissance for drilling operations.** LiDAR scans identifying slopes and feasible areas for drilling access could save time and effort, possibly reducing site visits.
2. **Geotechnical asset management inventory data collection.** LiDAR scans may prove to be an effective way to inventory and characterize slopes, embankments, and culverts.
3. **Change detection for use in forensic evaluations and monitoring.** LiDAR scans can be utilized to determine volumes, and when compared to previous scans, can detect changes. This would help identify slope failures and the extent of remediation efforts. The Vicksburg bridge, which is experiencing movement, would likely benefit from this technology.
4. **Cross-section data collection for stability analyses.** LiDAR scans could help create fast and efficient cross-sections for use in emergency scenarios where computer analyses and modeling are required for remedial actions regarding slope failures.

The first focal point of our research was on site investigation and reconnaissance during drilling operations. Traditional methods of data collection in challenging terrain often fall short in terms of accuracy and efficiency. By employing LiDAR technology, we aimed to enhance the precision of site reconnaissance, providing engineers with a detailed, real-time understanding of surface conditions and their relationship to access. This not only expedites decision-making but also ensures safer, more informed drilling operations.

Geotechnical asset management is another critical domain under scrutiny. The conventional inventory data collection processes face limitations in comprehensiveness and timeliness. Through the lens of LiDAR, this research explored expanding asset management by utilizing high-resolution data to create detailed inventories. Moreover, the study delved into LiDAR's application regarding change detection, enabling real-time monitoring and forensic evaluation of geotechnical assets for proactive maintenance and risk mitigation.

Further, the research investigated the integration of LiDAR for cross-section data collection, focusing on stability analysis. By capturing detailed terrain morphology and structural features, LiDAR facilitates a more nuanced understanding of geotechnical conditions, empowering engineers to make informed decisions about infrastructure stability and resilience. As part of our methodology, we extensively analyzed available data within DOTD and other Louisiana agencies. Additionally, we explored the synergy between LiDAR and drone technologies for local scanning, aiming to present a holistic approach to geotechnical data collection. This research aimed not only to showcase the transformative potential of LiDAR in geotechnical applications but also to provide actionable insights for its seamless implementation within DOTD. By the conclusion of this study, we anticipate offering a roadmap for a more sustainable and resilient geotechnical infrastructure, harnessing LiDAR's power for the long-term benefit of Louisiana's transportation and development initiatives.

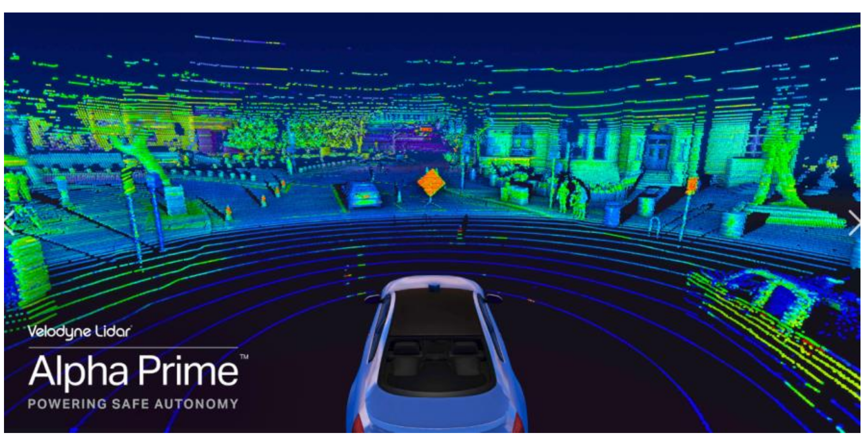
Literature Review

As a critical discipline in civil infrastructure development, geotechnical engineering continually seeks innovative technologies to improve the efficiency and accuracy of data acquisition and analysis. The integration of Light Detection and Ranging (LiDAR) technology has emerged as a promising solution, revolutionizing traditional geotechnical practices. This literature review explores the existing body of knowledge surrounding LiDAR applications in geotechnical engineering, with a particular focus on site investigation, asset management, change detection, and stability analysis within transportation and development agencies.

LiDAR is commonly utilized for engineering and transportation-related issues. The collected data is accurate, and the selected point cloud can provide information for visualization, mapping, and design. Examples of the technology in use are included below.

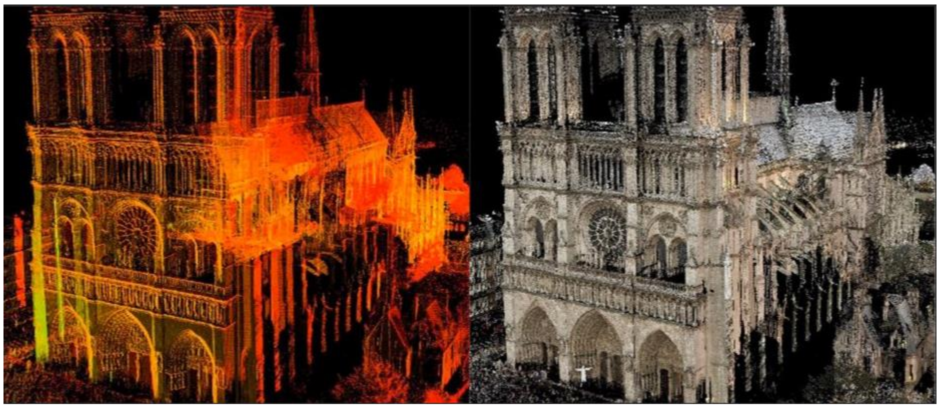
- **100 Applications for LiDAR.** This website provides 100 LiDAR applications. https://lidarradar.com/apps/100-applications-or-uses-of-lidar-technology. The list includes applications such as digital elevation models (DEM), vehicle automation, autonomous cruise control, gaming, military applications, roadway design, manhole scanning, police speed guns, crime scene reconstruction, and architectural purposes. For example, Figure 1 shows how Velodyne LiDAR enables an autonomous vehicle to map and navigate the environment.

Figure 1. Velodyne LiDAR [1]



- **Notre Dame Cathedral.** Notre Dame Cathedral was scanned with LiDAR prior to the catastrophic fire of 2019. The data collected helped conservators with important information regarding the truss structure and repair operations; see Figure 2. Laser-scanning technology can create exceptionally detailed 3-D models of cultural sites, bringing them to life online and helping experts restore them if disaster strikes [2]**.**

Figure 2. LiDAR images of Notre Dame Cathedral [3]



- **National Consultants.** Consultants such as BGC Engineering (BGC) utilize LiDAR to inform risk management decisions. Examples of how the data can be utilized include airborne LiDAR scans, which have been analyzed by BGC [4] to conduct change detection mapping, comparing temporal LiDAR data sets with their patent-pending change detection algorithm to calculate positive and negative change over the area [4]. Having this information helps BGC and its clients assess the potential risks of slope failures, debris flows, etc. Similar data sets could be created for slope failures along a highway or geotechnical asset. In addition to aerial, mobile, and terrestrial LiDAR, volumetric comparative surveys are also possible. These comparative studies would allow for volume (e.g., stockpiles, borrow pits, etc.) and/or change detection (e.g., slope changes) to support failure surface identification.
- **BGC** [4] is also involved in the Geotechnical Asset Management (GAM) efforts growing across the country and led the Transportation Research Board (TRB) Committee, AFP00(1), on GAM. The goal of GAM is to manage assets such as earth retaining walls, slopes, culverts, etc., so that highway corridors remain open and efficient for transportation. LTRC began GAM efforts by inventorying earth retaining walls as a pilot dataset in their recent research [5]. Other GAM datasets (e.g., slopes, embankments, culverts) should be inventoried, and LiDAR could be an efficient means of collecting this data for DOTD. Data collected along Louisiana highways for other purposes could

benefit the DOTD Geotechnical Section. The link below references an example of how the data can be utilized: https://bgcengineering.ca/change_detection-_mapping_services.html.

- **GeoStabilization Inc. (GSI)** has been tasked to repair several Louisiana DOTD projects with slope issues and sketch 3-D imagery of the before and after repaired conditions. These documents have been uploaded to the DOTD OpenGround database. GSI's Will Brantley conducted several slope stability analyses and repairs. During these investigations, GSI utilized remote sensing and drone photogrammetry to detect and characterize these slopes, when necessary, and to access LiDAR technology. There may also be times when DOTD wants to conduct LiDAR studies in-house due to timing and/or cost constraints. Access to LiDAR technology and its deeper incorporation into DOTD practices have benefits. Small-scale LiDAR scans could supplement and define with more precision problematic slopes that may be difficult or hazardous to access.
- **Wheaton College.** Students at Wheaton College in Illinois used LiDAR to map excavations at a historic site in Tel Shimron, Israel. The group developed a mobile backpack to document each day's dig efforts. The LiDAR scans created high-quality scans to show the difference and volumes of earth moved during the excavation [6].
- **Washington State Department of Transportation (WSDOT).** Through the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT), WSDOT conducted research studying the potential benefits of LiDAR. The report showed that cost efficiencies could be realized over time [7].
- **Louisiana Geological Survey (LGS).** LGS notes that LiDAR imagery is extremely useful for geologic mapping of the Quaternary units predominant in Louisiana because it provides a detailed, uniform view of the morphology of their surfaces. LiDAR observations can also be used to infer relative age and correlate terraces and their underlying depositional units, which are often difficult to discern using other imagery because temporal and areal variation in soil moisture, vegetation, land use, and other factors drastically change how well construction land forms can be seen. LGS believes that the availability of LiDAR imagery enables significant improvement and refinement in geologic interpretation [8].
- **Local Consultants.** Forte and Tablada, Inc. (F&T) is a Louisiana-based firm with access to LiDAR technology (terrestrial, aerial, and mobile). F&T assisted with major repairs to the Sunshine Bridge as a result of a barge crane collision. Former DOTD Bridge Design Engineer Administrator Jenny Fu recently delivered a presentation highlighting LiDAR's

speed and accuracy during repair operations. F&T's 3-D scanning of the Sunshine Bridge allowed measurements to be collected away from the damaged structure with accuracy and precision, and real-time measurements during the jacking and loading of the frame structure to ensure element behavior proceeded as desired [9]. F&T also conducted LiDAR scans of the Brookhill Ferry shipwreck that was revealed along the east bank of the Mississippi River near downtown Baton Rouge, LA, when the river dropped to historically low levels; see Figure 3. They produced a website for viewers to explore the wreckage through an easy-to-use interface of the LiDAR dataset. [10]

Figure 3. 3-D laser scanning of the Brookhill Ferry Shipwreck, Baton Rouge [10]

- **DOTD.** In addition to the consultant services outlined previously, DOTD recently conducted LiDAR surveys in Lake Charles and Bossier Parish, LA.
  - **Lake Charles** (Original notification, August 9, 2021)—The Louisiana Department of Transportation and Development announces that motorists may see slow-moving traffic during non-peak hours along portions of I-10 in Calcasieu Parish on August 16 and August 17, 2021. This work is scheduled to survey I-10 as part of the I-10 Calcasieu River Bridge Replacement project.

    Crews will travel along I-10 between the I-10/I-210 west interchange and the Ryan Street exit ramp, scanning the corridor with Mobile Light Detection and Ranging

(LiDAR) technology. LiDAR scanning is a surveying method that measures distance using laser light to produce digital 3-D representations of the intended target.

The Mobile LiDAR method is extremely cost-effective for the state, as it will expedite the delivery of topography surveys to DOTD designers, prevent multiple lane closures throughout the corridor, and reduce the number of conventional survey crews needed to perform the survey. DOTD has used this technology in previous projects throughout the state, and it has been proven to be a useful tool in the Topography Survey Process.

This activity will not include any lane closures; however, it will cause traffic to slow down due to police blocking traffic, similar to a funeral procession. The mobile LiDAR scanning will continue throughout the day, driving along the surface streets and interstate in the vicinity of this project [11].

— **Bossier Parish**—DOTD to conduct LiDAR scanning on Thursday on I-20/I-220 in Bossier Parish [12]. The Louisiana Department of Transportation and Development will begin surveying work Thursday morning as part of the environmental portion of the I-20/I-220 Barksdale Air Force Base (BAFB) Interchange project in Bossier Parish. Crews will be traveling along I-20 eastbound and westbound, as well as I-220 in the vicinity of the interstate interchange, while the Mobile Light Detection and Ranging (LiDAR) vehicle travels, accompanied by two Louisiana State Troopers. The LiDAR scan will also be utilized on the interstate ramps.

The LiDAR method measures distance by using laser light to create digital 3-D representations of the target. DOTD has used this technology in previous projects throughout the state, and it has been proven to be a useful tool in the Topography Survey Process.

“The technology involved in this process will greatly speed up the survey work that typically would take anywhere from four to six months,” said Erin Buchanan, public information officer with DOTD. “They’re going to be gathering those images in a matter of a day. The benefits of this are that it's very cost-effective, and we won’t have an entire surveying crew on-site working for months on end to gather the same images.”

Because the LiDAR vehicle must operate slowly, motorists may encounter a traffic slowdown in this corridor, similar to a funeral procession, though there will be no lane closures. Surveying work is weather-dependent, and should take place on May 31 from approximately 7:00 a.m. to 3:00 p.m., during non-peak travel times.

Buchanan said the vehicle works similarly to that of a Google Maps car. “There’s a camera mounted on top, and they will be traveling the interstate at the minimum interstate speed,” she explained. “If you’re on the interstate or around the interchange at I-20/220, you might see that vehicle. There won’t be any lane closures associated with this.”

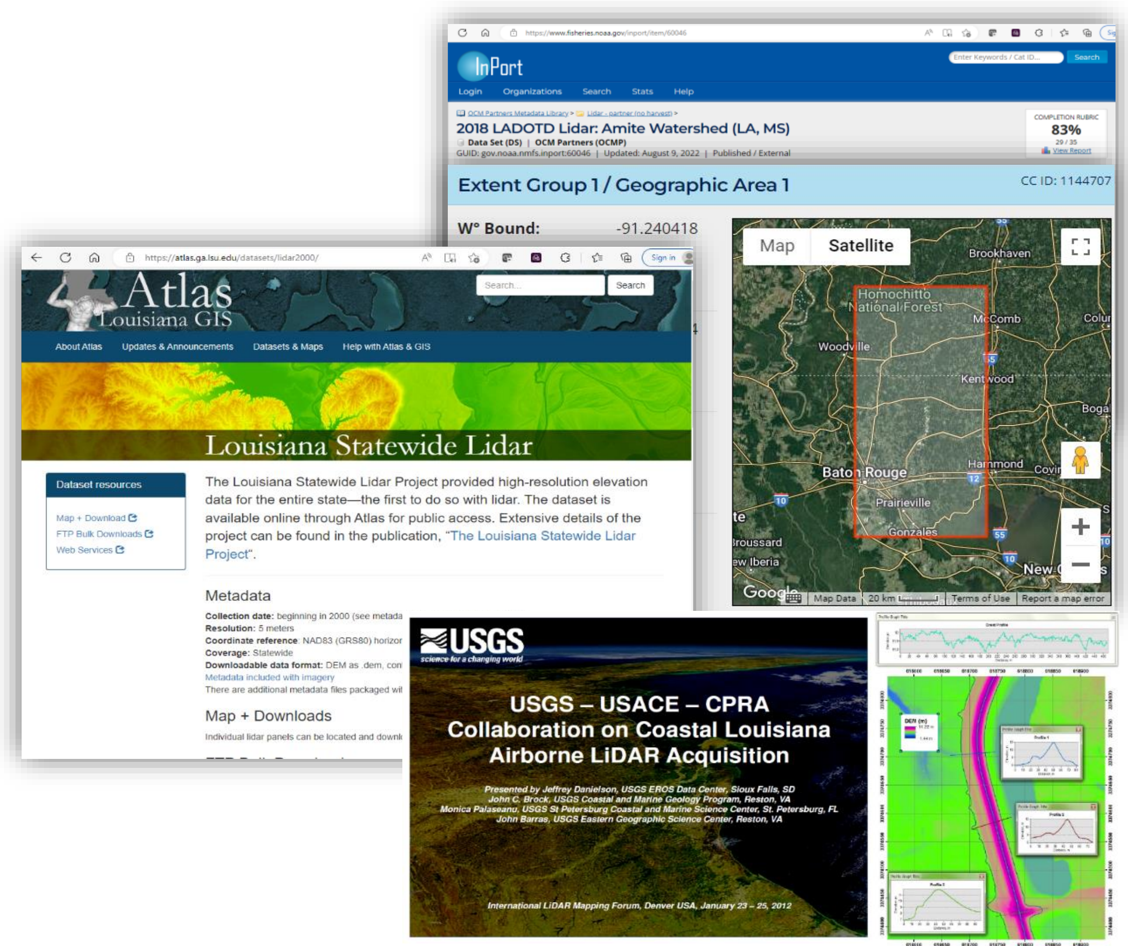
Figure 4. Vehicle used for DOTD’s LiDAR scanning as part of the I-20/I-220 Barksdale Air Force Base (BAFB) Interchange project in Bossier Parish [13]

Numerous sources of LiDAR data are available online. A brief collection is listed below. LTRC compiled a list with links, attached as an Appendix, for reference by DOTD staff.

- Airbus defense and space
- Atlas Louisiana GIS
- Bhuvan Indian Geo-Platform of ISRO
- Digitalglobe
- DigitalGlobe Open Data Program
- DOTD Geographic Information Systems (GIS)
- Earthdata (NASA)
- Earthquake Engineering Research Institute (EERI)
- Esri
- Geographic Information Systems Laboratory
- GeoRef
- Geotechnical Data Hub
- Global Forest Watch
- Google Earth
- Here
- JAXA’s Global ALOS 3-D World
- DOTD
- Local consultants, such as BGC Engineering
- Local consultants, such as Forte & Tablada

- Maxar
- Multi-Resolution Land Characteristics (MRLC) Consortium
- NASA Earthdata Search
- NASA Worldview
- National Center for Airborne Laser Mapping (NCALM)
- National Geospatial-Intelligence Agency (NGA)
- National Geotechnical Experimentation Sites (NGES)
- National Geotechnical Properties Database
- National Institute for Space Research (INPE)
- National Renewable Energy Laboratory (NREL)
- NEON Open Data Portal
- Next Generation Liquifaction (NGL)
- NOAA CLASS
- NOAA Data Access Viewer
- NOAA Digital Coast
- NOAA Digital Coast
- NSF-Designsafe
- OpenTopography
- planet.com
- Satellite Land Cover
- Sentinel Open Access Hub
- The European Space Agency (ESA)
- The National Ecological Observatory Network (NEON)-Spatial Data and Maps
- UNAVCO
- United States Geological Survey 3-D Elevation Program (USGS 3DEP)
- USACE-ERDC
- USGS (United States Geological Survey)
- USGS-3DEP LiDARExplorer
- U.S. Interagency Elevation Inventory
- VITO Vision
- 100 applications for LIDAR

Figure 5. Examples of LiDAR source data

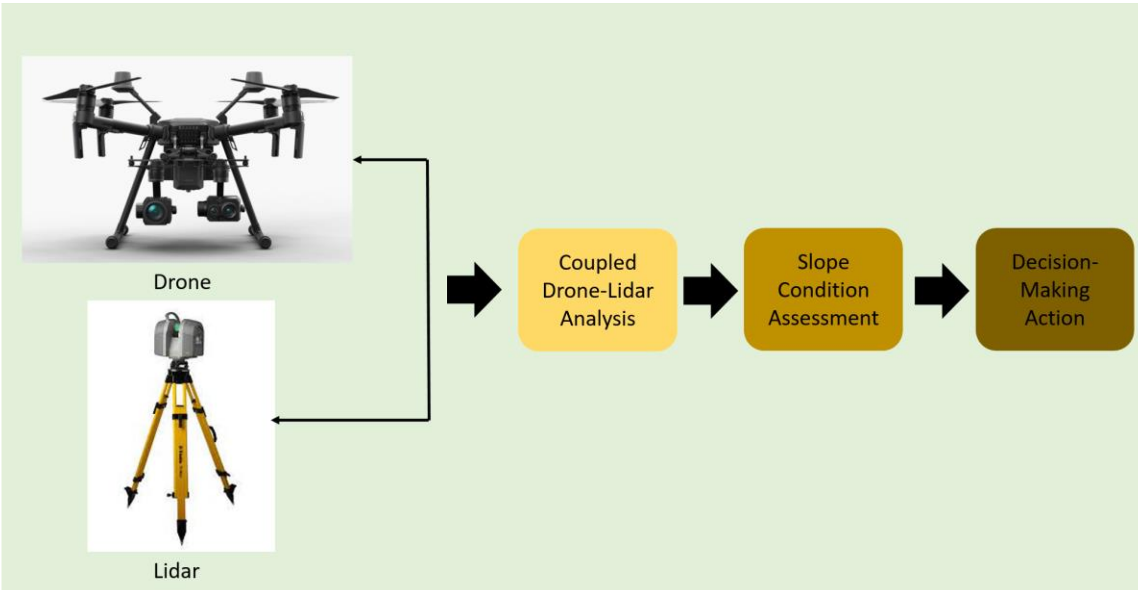


- **Hardware, Software, and Drone Services.** In addition to the consultant services outlined previously, there are providers of hardware and software available. Some of the hardware may be relatively expensive compared to contract services; however, it may benefit the Department if this technology is available in-house at DOTD. The DOTD Location and Survey section is familiar with the technologies, and the DOTD Aviation section has already assisted LTRC with drone services through previous research, Cost-Effective Detection and Repair of Moisture Damage in Pavements [14].

  Drones can offer inventory, susceptibility mapping, 3-D imaging photogrammetry, digital elevation model development, reconnaissance, and Orthophoto image development (Digital Orthophoto Model (DOM)). On the other hand, LiDAR with thermal cameras can offer sensitivity to moisture and temperature in the slope soil body.

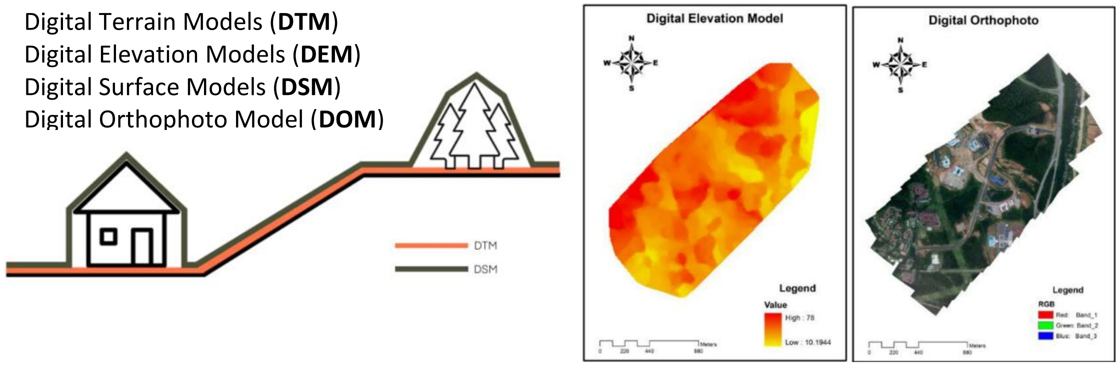
  Field investigations on slopes with remote sensing technology, specifically using drones with LiDAR thermal camera sensors, can be used as slope field performance monitoring and condition assessment prior to failure as a proactive measurement approach for sustainable decision-making action; see Figure 6. Drones also offer a safe alternative to actual site operations where traffic or steep slopes may limit pedestrian activity.

Figure 6. Remote sensing approach workflow



This field remote sensing approach should be able to: (1) identify hot spot zones in the slope; (2) detect the vulnerability as crack, void, soil movement, surface elevation, and/or soil moisture variation; (3) assess the slope's condition through performance monitoring at varying time and spacing intervals; (4) develop remote sensing-based correlations with soil moisture and soil suction; and (5) develop Digital Terrain Models (DTM), Digital Elevation Models (DEM), and Digital Surface Models (DSM) through Drone LiDAR and photogrammetry; see Figure 7.

Figure 7. Drone LiDAR and photogrammetry outcomes

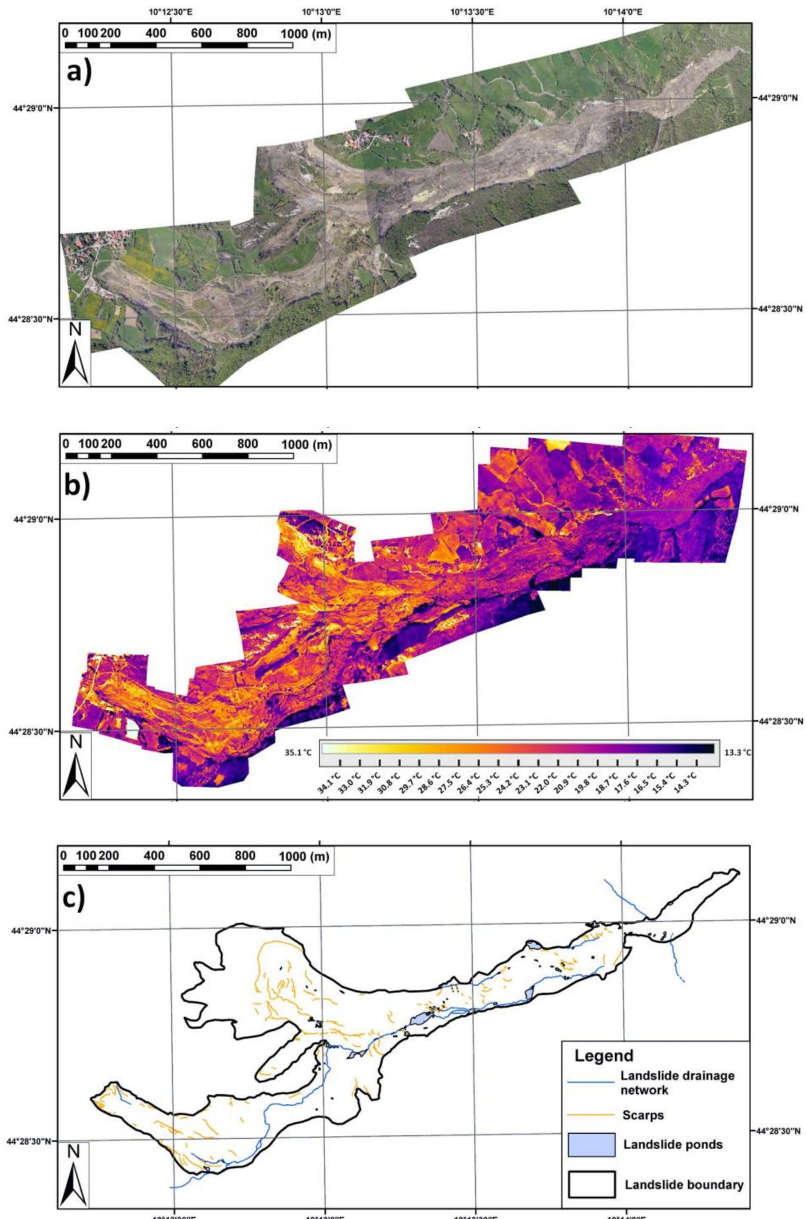


- **Development of Drones with Selected Cameras and Sensors.** In the past, satellites or aircraft have been the primary means of remote sensing, collecting information from a distance. Although still relatively new, the use of drones equipped with remote sensors for site characterization is spreading rapidly due to significant technological advancements. It is necessary to have a fundamental grasp of the deployed instruments (LWIR camera, LiDAR photogrammetry software, multispectral and hyperspectral camera, visible spectrum camera), as well as how the sensors gather data, in order to use remote sensing. The most common drone-produced products are visible spectrum aerial photos and videos, but a drone can also carry multiple sensors. Remote sensors are often divided into two categories: passive sensors and active sensors. A specific EM spectrum is recorded by passive sensors from reflected ambient light. The red, green, blue, near-infrared, red-edge, and Long-Wave Infrared (LWIR) bands are the most frequently employed. Visible spectrum cameras, multiple spectrum cameras, hyperspectral cameras, and LWIR band cameras are a few examples of passive sensors. When a signal from active sensors returns to the source, it is picked up. Active sensors commonly used today include Radio Detection and Ranging (RADAR) and LiDAR.
- **Photogrammetry Using Optical Camera.** Software can extract 3-D information from 2-D photos using methods such as georeferenced orthomosaics, point clouds, triangulated irregular networks (TINs) meshes, digital elevation models (DEMs), and digital terrain models (DTMs). Thus, it is possible to create 3-D models from images with high overlap taken from multiple positions, even without spatial orientation.
- **Photogrammetry Using Thermal Camera.** Similar to conventional electro-optical cameras, thermal camera sensors also produce an image or digital copy of what they view, but instead of capturing light wavelengths to which our eyes are sensitive, they capture heat as infrared radiation. The images produced by thermal cameras appear

strikingly different from what we see with our eyes because they are designed to detect and display heat zones invisible to the human eye. Standard thermal imaging devices display blue to red streaks, with each color reflecting a distinct temperature produced by individuals, buildings, and objects; see

- Figure 8. Lower-temperature regions are depicted in blue, whereas higher-temperature regions are in red. On the other hand, some thermal cameras employ various color schemes.

Figure 8. Sample thermal imaging investigation results



- **Surveying Pads.** Drone position data is needed to create a correctly scaled and geographically positioned dataset. The GPS and the Inertial Measurement Unit (IMU) are two instruments essential for verifying the accuracy of collected data. The GPS keeps track of the drone's location, while the IMU accounts for roll, pitch, and yaw. Together, these devices track the flight's geographic coordinates and are essential for post-processing data. There are numerous GPS systems available, including Ground Control Points (GCPs), real-time kinematic (RTK) GPS, and Satellite Navigation Systems

(GNSS), which is another name for GPS; see Figure 9. Ground control points (GCP) are a useful tool for georeferencing drone data, considerably enhancing GPS navigational accuracy. Images without geographic coordinates can also use this technique. In post-processing software, this technique requires manual identification of surveyed ground targets. Temporary targets are frequently used; however, GCPs can also be clearly apparent across multiple photographs. Ground control-produced goods can help improve accuracy to less than 0.1 feet in both horizontal and vertical directions. Additional targets can be identified and added as checkpoints in software applications. The software uses checkpoints to measure inaccuracy between calculated and surveyed coordinates, not to georeference the point cloud.

Figure 9. Sample surveying pad during field imaging

The LTRC pavement group utilized ArcGIS Drone2Map for their research in Project 18-1GT. Since DOTD has access to ArcGIS, this would be the more economical option compared to Pix4D, depending on the service features. This software was primarily utilized for their moisture measurements. This same software may be utilized for this project's LiDAR research.

ArcGIS Drone2Map is the desktop app for geographic information system (GIS) drone mapping needs. One can use any modern drone to capture high-resolution imagery whenever and wherever needed. Immediately after the flight in the field, process images on your laptop and perform drone analytics on your natural-color, thermal infrared, or multispectral datasets. As part of the ArcGIS system, Drone2Map provides easy access to a range of tools and capabilities for accurate mapping and geospatial analysis. As a 2-D and 3-D photogrammetry app, Drone2Map lets you create the outputs you need, including orthomosaics, 3-D point clouds, and textured meshes, then easily share them with your ArcGIS organization for greater collaboration and awareness [15].

- **Software.** Software solutions exist through these consultants and other sources. Specifically, GSI utilizes a product called Pix4D. Pix4D is "a unique photogrammetry software suite for mobile and drone mapping" [16]. DOTD likely has other in-house solutions available. This research (global mapping) will investigate possible applications and the effectiveness of these alternatives.

- **DOTD Applications.** This research investigated LiDAR for several geotechnical applications.

  — **Site investigation and reconnaissance for drilling operations and design.** LiDAR scans identifying slopes and feasible areas for drilling access could save time and effort, possibly reducing site visits. Currently, the DOTD drilling coordinator has access to a GPS. This is primarily for latitude and longitude coordinates, but elevations are also collected for scour and design reference. These measurements provide single/discrete point measurements vs. LiDAR full-area 3-D scans. LiDAR scan information could provide additional cross-section data and slope information to assist with site access of the drill rig and/or cone penetration test (CPT) rig.

  LiDAR scans could also benefit scour calculations by providing an accurate depiction of the existing terrain relative to boring location and to scour depths. Calculation adjustments are made based on the differences between the datum, ground surface, and scour depth elevations. LTRC research is updating the CPT software to utilize these different elevations. Using LiDAR data to create an accurate site picture will also improve design analyses and interpretations.

  — **Geotechnical Asset Management inventory data collection.** The recent GAM research by LTRC inventoried only earth-retaining walls. LiDAR can be an effective tool for inventorying and characterizing embankments, slopes, and culverts. Collecting the length and steepness of these assets would help determine their location and properties. The data likely already exists in other DOTD scans/data; it just needs to be accessed. These characteristics are important components of appropriate asset management, including the necessary funding and efforts these assets might require (e.g., labor, design, detours, etc.) as they age.

- **Change detection for use in forensic evaluations and monitoring.** LiDAR scans can be used to determine volumes and, when compared with previous scans, can detect changes. These analyses would help identify slope failures (length, height, direction, rate, etc.) and the possible extent of necessary remediation efforts.

  There are two major bridges along the Louisiana-Mississippi border: the Natchez Bridge and the Vicksburg Bridge. The Mississippi Department of Transportation (MDOT) is responsible for the Natchez Bridge, and Louisiana DOTD is responsible for the Vicksburg Bridge. Unfortunately for DOTD, the Vicksburg Bridge is experiencing significant foundation movements due to its geology and historic features. A massive effort in instrumentation and monitoring is underway at the site; however, due to the slopes and movements, hand surveying is difficult for reasons related to access and labor. Aerial surveys, including LiDAR, would provide a safe and effective way to collect data across the site and provide data for proactive analyses and remedial efforts. Other small sites would also benefit from quick data collection with minimal safety risks to DOTD or other staff.

  Because the Vicksburg site is so large, the utilization of aerial LiDAR would allow for resilient benchmarks located outside the failure zone. A drone with LiDAR capabilities could also scan the slope at regular intervals to assist with change detection and monitoring. Additionally, if real-time monitoring is necessary, Continuously Operating Reference Stations (CORS) like those implemented through the Bayou Corne Sinkhole project could be added and coordinated with the LiDAR data [17]. Cellular data can be added to CORS for data alerts and warnings based on chosen thresholds. The Vicksburg site will be a specific test location for this project.

- **Cross-section data collection for stability analyses.** LiDAR scans could help create rapid, efficient cross-sections for use in emergency scenarios where computer analysis and modeling are required for remedial actions related to slope failures. Cross-section data collection for stability analyses and remediation actions regarding slope failures.

  Collaborations within DOTD, specifically between the Geotechnical section and the Dam Safety and/or Bridge sections, would be beneficial, as they would provide tools to analyze slopes and their potential for failure. LiDAR scans could be used to generate accurate cross-sections for input into slope stability software.

Objective

The overarching objective of this research was to comprehensively evaluate the potential and effectiveness of Light Detection and Ranging (LiDAR) technology in enhancing geotechnical engineering practices within the Louisiana Department of Transportation and Development (DOTD). Building upon the insights presented in the abstract, introduction, and literature review, the research aimed to achieve the following specific objectives:

- **Evaluate LiDAR's impact on site investigation and reconnaissanc**e. Assess the efficiency and accuracy of LiDAR technology for site investigation and reconnaissance during drilling operations in challenging terrain. Compare LiDAR-based data acquisition with traditional methods to enhance precision and real-time understanding of subsurface conditions.
- **Examine LiDAR's contribution to Geotechnical Asset Management.** Investigate the role of LiDAR in geotechnical asset management, focusing on inventory data collection. Analyze the potential for LiDAR to create detailed inventories of geotechnical assets, facilitating proactive maintenance and risk mitigation strategies.
- **Explore change detection for forensic evaluations and monitoring.** Explore LiDAR's capabilities in change detection for continuous monitoring and forensic evaluations of geotechnical assets. Develop and implement change detection algorithms to assess structural deformations, erosion, and other alterations over time.
- **Investigate LiDAR for cross-section data collection.** Examine the application of LiDAR in cross-section data collection for stability analysis. Evaluate the utility of LiDAR-derived data in assessing slope stability, geological hazards, and overall infrastructure resilience.
- **Assess synergy between LiDAR and drone technologies.** Investigate the synergy between LiDAR and drone technologies for local scanning. Explore the feasibility and cost-effectiveness of integrating LiDAR with drone-based scanning, comparing the results with traditional data collection methods.
- **Utilize available data within DOTD and other Louisiana agencies.** Analyze available geotechnical data within DOTD and other relevant Louisiana agencies. Evaluate the compatibility and integration of LiDAR data with existing datasets to enhance geotechnical engineering practices.

- **Explore LiDAR implementation for sustainable and resilient infrastructure.** Based on research findings, identify and propose actionable strategies for implementing LiDAR technology in geotechnical infrastructure within DOTD. Assess the potential for LiDAR to contribute to sustainable, resilient infrastructure in the long term.

By achieving these objectives, the research aimed to provide Louisiana DOTD with a comprehensive understanding of the practical applications, benefits, and challenges associated with LiDAR technology in geotechnical engineering. The outcomes of this study will inform decision-makers and practitioners, guiding the integration of LiDAR into existing practices for improved infrastructure management and resilience.

Ensuring the accessibility of LiDAR-derived data is as critical as the collection itself. Beyond the immediate project team, other DOTD divisions, partner agencies, and research collaborators will require streamlined access to information for planning, design, and monitoring. A key goal is to tap into all existing scans and make them accessible to DOTD sections, ensuring that new LiDAR data is not siloed but instead integrated with the Department's broader datasets. This should be supported by a dedicated database management system for LiDAR applications in geotechnics, allowing users to retrieve and overlay 3-D scans, cross-sections, and change-detection analyses with drilling records, scour measurements, and geotechnical asset inventories. By standardizing data formats and linking them to metadata, the system will enable engineers, dam safety specialists, and bridge teams to visualize terrain conditions in real time and compare them with historical datasets to assess trends, prioritize maintenance, and justify funding allocations. A secure but open-access structure, modeled after existing DOTD GIS portals, will maximize usability across divisions while ensuring quality control and alignment with agency protocols.

Scope

This multifaceted research effort aims to investigate the integration of Light Detection and Ranging (LiDAR) technology into geotechnical engineering practices within the Louisiana Department of Transportation and Development (DOTD). The scope is defined by the following key components:

- **Utilization of available data within DOTD and other Louisiana agencies.** The study extensively utilized existing geotechnical data within DOTD and other relevant Louisiana agencies. This includes geospatial information, geological surveys, and historical data related to site investigations, drilling operations, and infrastructure stability assessments.
- **Analysis of LiDAR technology for site investigation and reconnaissance**. The research focused on assessing the effectiveness of LiDAR in site investigation and reconnaissance during drilling operations. LiDAR-derived data was compared with traditional methods to evaluate its accuracy and efficiency in providing real-time subsurface information, especially in challenging terrains.

  The project makes LiDAR data widely accessible by compiling existing scans to Section 67 and creating a list of resources and tools for geotechnical applications. This will standardize and integrate LiDAR outputs with other DOTD datasets, allowing engineers and divisions (e.g., Bridge, Dam Safety) to easily access 3-D scans, cross-sections, and change-detection analyses. In turn, this will improve real-time visualization, trend analysis, and decision-making while ensuring quality control through a secure, DOTD-managed platform.
- **Investigation of Geotechnical Asset Management using LiDAR.** A critical aspect of the study involved evaluating LiDAR's contribution to Geotechnical Asset Management. The research involved creating detailed inventories of geotechnical assets using LiDAR-derived data. This analysis aims to enhance current asset management practices for improved infrastructure resilience.
- **Change detection and continuous monitoring with LiDAR**. The study explored LiDAR's capabilities in change detection for continuous monitoring and forensic evaluations of geotechnical assets. Change detection algorithms were investigated and implemented to assess structural deformations, erosion, and alterations over time.
- **Application of LiDAR in cross-section data collection**. The research investigated the application of LiDAR in cross-section data collection for stability analysis. LiDAR-

derived data were analyzed to assess their utility in evaluating slope stability, geological hazards, and overall infrastructure resilience.

- **Exploration of LiDAR and drone technologies synergy**. An essential component of the research involved exploring the synergy between LiDAR and drone technologies for local scanning. The feasibility and cost-effectiveness of integrating LiDAR with drone-based scanning was assessed, providing insights into alternative data collection methods.
- **Analysis of research findings and LiDAR implementation strategies**. The study culminated in the analysis of research findings, identifying opportunities and challenges associated with LiDAR implementation in geotechnical infrastructure within DOTD. Actionable strategies for integrating LiDAR into existing practices are proposed, emphasizing the potential for sustainable, resilient assets in the long term.

Throughout the scope of work, collaboration with DOTD and relevant Louisiana agencies was maintained to ensure access to pertinent data and to align the research outcomes with practical considerations for implementation. The research aims to provide valuable insights to optimize geotechnical engineering practices within DOTD through the strategic integration of LiDAR technology.

Methodology

Task 1: Research existing local, state, and federal efforts regarding LiDAR.

The research investigated the utilization of LiDAR within DOTD and other agencies. The DOTD Location and Survey section, led by Administrator Stan Ard, was a valuable resource for this existing information. The research team received assistance from staff members Steve LeBlanc, Jeremy Penton, and Dustin Smith, each of whom has expertise in geographic information systems (GIS) and data collection.

With DOTD collecting data frequently across the state, different LiDAR datasets can be compared to identify changes in earthen slopes. This may require software to open and view this data within the Geotechnical section. This was researched and outlined as part of the project. Data interfaces were explored to tap into this data for geotechnical applications, including Geotechnical Asset Management.

The DOTD Aviation section has assisted LTRC with other recent projects, as they have access to drones and the necessary flight licenses, permits, etc. The LTRC Pavement group has combined multiple cameras with the drone as part of LTRC Project 18-1P. This project investigated drone-based scans combined with LiDAR. Small-scale drone LiDAR scans are possible and can be collected to supplement and define, with greater precision, problematic slopes that may be difficult or hazardous to access. Connections with DOTD Aviation staff were established to secure their support throughout this project.

Researchers also met with local consultants to examine available resources and capabilities. These included Forte & Tablada, GSI, and other companies currently using LiDAR technologies. Consultants are often hired by DOTD and can provide valuable insight.

Task 2: Determine the applicability and implementation potential of LiDAR for geotechnical applications within Louisiana.

After examining internal and external resources, LTRC reviewed these applications and determined which have the most potential for geotechnical applications within DOTD.

Researchers held PRC meetings to discuss their findings and determine the best course of action and the optimal cost/benefit ratio. This helped to direct efforts, including assistance from the included LSU Research Associate.

Task 3: Conduct slope performance monitoring using remote sensing via drone and LiDAR.

The Vicksburg Bridge is an ideal site to utilize drone and LiDAR technologies. The bridge and the surrounding slope are still experiencing movement and are under others' monitoring efforts. The site is vast and would benefit from multiple aerial collections. The active site is relatively steep in some areas, with over 100 feet of difference from the river to the top of the slope. The slope and terrain reduce the speed/effectiveness of physical hand surveying readings.

The measurements can be used to monitor slope over time, and researchers planned to take multiple measurements of the same terrain for comparison. The multiple LiDAR surveys were also valuable for generating digital terrain models (DTMs) for stability analysis and plan development. Researchers worked with the DOTD Survey section, Aviation section, and LTRC Pavement group.

The research evaluated and compared the cost and efficiencies (e.g., speed, quality, interface, etc.) of LiDAR versus other technologies. Early warning systems are also available, as CORS were used with cellular connections during the 2012 Bayou Corne sinkhole. [17]

The research investigated the option of acquiring a drone for use by the LTRC Geotechnical and HQ Geotechnical groups. There are costs and training associated with drones, but the advantage of a rapidly deployable drone is that it can produce more data on schedule. Pavement researchers who utilized the Aviation section's drone service indicated that scheduling flights was at times difficult due to the section's existing schedule. A drone within the LTRC Pavement and Geotechnical groups would be available at the group's discretion and need.

Task 4: Connect information with the Geotechnical Database.

LTRC has been working closely with the DOTD Geotechnical group for some time to build a geotechnical database. The database has made remarkable progress over the years, especially with the addition of Bentley OpenGround. The researchers attempted to connect LiDAR to the geotechnical database as an information source for designers. OpenGround® has geographic information system (GIS) capabilities that will connect with other sources. Rather than developing new tools, efforts focused on connecting with the existing structures as much as possible.

Task 5: Recommend and implement strategies.

Recommend steps to continue the research efforts to realize efficiencies (e.g., time, data, productivity, etc.) within the Department. Implementation strategies were developed with the Project Review Committee (PRC) and guided by the researchers and stakeholders to the end users. Recommendations for best practices and those that meet Section 67 needs are at the forefront. Drone utilization options, including DOTD services, retainer consultant contracts, or LTRC Pavement and Geotechnical group ownership, were evaluated, reviewed, and implemented.

Discussion of Results

DOTD Section 67 and Section 30

During the initial Project Review Committee (PRC) Meeting, LTRC coordinated discussions between Section 30, the DOTD Location and Survey section, and Section 67, the DOTD Geotechnical Design section, to establish and refine project goals. Section 30 was a valuable resource for the project, as they are the key holders for LiDAR and other geospatial technologies within and beyond DOTD.

Available LiDAR and Digital Survey Tools List

As part of the research, LTRC coordinated with Section 30 to identify available LiDAR resources within DOTD and publicly accessible platforms. These discussions highlighted that a wide range of tools and data sources already exist, both internally and externally. Developing a structured summary of these resources would benefit Section 67 and Section 30 by improving accessibility and usability.

In addition to existing LiDAR data, several other available tools can be used to extract digital survey data for locations across Louisiana; see Appendix Part III. These tools allow users to obtain digital surveys, geometric information, resolution/precision, time-based data, and other relevant site characteristics that can support engineering analysis. This list of tools will provide Section 67 with access to available in-house site data for baseline information (e.g., projects in situ data) and digital-based supplements to support design decisions.

On a broader level, this research will serve as a shared resource across all DOTD divisions for future efforts. By connecting the Department Districts and Bridge and Pavement sections, the information will enhance collaboration and provide a unified view of geotechnical and structural conditions. Further, these available in-house data sources and LiDAR tools can be integrated as a complementary module within a future database framework (e.g., OpenGround), enabling additional data collection and analysis for specific regions across Louisiana. This approach ensures that DOTD can leverage both in-house and publicly available data to support more efficient and informed decision-making.

Drone Acquisition

LTRC intended to purchase a LiDAR drone for the research, but due to limited funds, the purchase was not approved. Section 30 was helpful throughout the research for drone scans, but their availability was limited at times. Ideally, drones would be available for use when necessary, but there are several limitations, including the cost of acquisition and the frequency of need. DOTD Districts are beginning to acquire drones for their use since they are away from HQ and Section 30. Drone acquisition will require careful planning before it can be fully implemented within all DOTD workflows. Additionally, licensure and DOTD policy play a role in the implementation of drones. Appendices Part I and II present the DOTD policy regarding Uncrewed Aerial Vehicles (UAVs).

For this research, the first step was to coordinate short- and long-term drone scheduling and use, and establish a process for Section 30 to collect data, similar to the one used during their field visit in Vicksburg. However, several considerations must be addressed to ensure successful implementation. Drone equipment operation and maintenance costs, both short- and long-term, are primary factors, as both require funding. Additionally, training requirements must be met so that staff are properly certified to operate drones and process LiDAR data. Having a drone available at a moment's notice is ideal, but not always practical, and having an experienced pilot can make or break a dataset. Currently, training and acquiring a drone remain on the LTRC Geotechnical group's wish list, highlighting the need for administrative alignment and resource allocation. From a technical perspective, construction site variability and field conditions highlight the importance of capturing accurate, site-specific data using drone-based LiDAR systems. Together, these elements illustrate that while drone acquisition has significant potential to improve efficiency and safety in geotechnical investigations, it will require coordinated investment, training, and technical validation before full deployment.

Coordinating Drone/LiDAR Use. LTRC researchers met with stakeholders to determine a clear, efficient workflow to guide Section 67 toward access to LiDAR or drone scans from Section 30, as well as how Section 30 could benefit from this collaborative research.

The process would begin with Section 67 submitting a request whenever a scan is needed. This request should specify the project location, purpose, and type of deliverables required (e.g., raw scans, processed cross-sections, or interpreted slope stability outputs).

For Section 30, the request would trigger an internal workflow:

- Check the available Section 30 scans**.** Determine if existing LiDAR data already covers the requested area.
- If data exists, provide access and offer technical support for interpretation if needed.
- If data does not exist, identify options:
  - — Schedule new drone/LiDAR scans in-house

— Coordinate with DOTD-approved vendors to rent or contract the survey

— Use external public sources (e.g., ATLAS or federal repositories) to supplement missing data

Once the data is obtained, Section 30 would process and interpret it using approved tools and workflows, then deliver both the raw and interpreted results back to Section 67. This ensures that Section 67 can use the data directly in geotechnical projects such as design, drilling coordination, or slope stability analyses.

The benefit to Section 30 is twofold:

- Section 30 continues its central role in managing and interpreting LiDAR datasets, which strengthens its technical expertise and visibility within DOTD.
- They also expand their resource pool by creating standardized procedures, shared databases, and cross-training opportunities that support future projects beyond Section 67's (and other sections') immediate needs.

A flow chart outlining the process would benefit other sections by showing the logical flow of requests through Section 30, the data checks and decision points within Section 30, and the feedback loop that delivers results back to the requesting section. This not only ensures efficiency and accountability but also maximizes the value of LiDAR and drone resources across the Department. These resources could be made available via the intranet to DOTD personnel.

Efforts to Interpret the Data

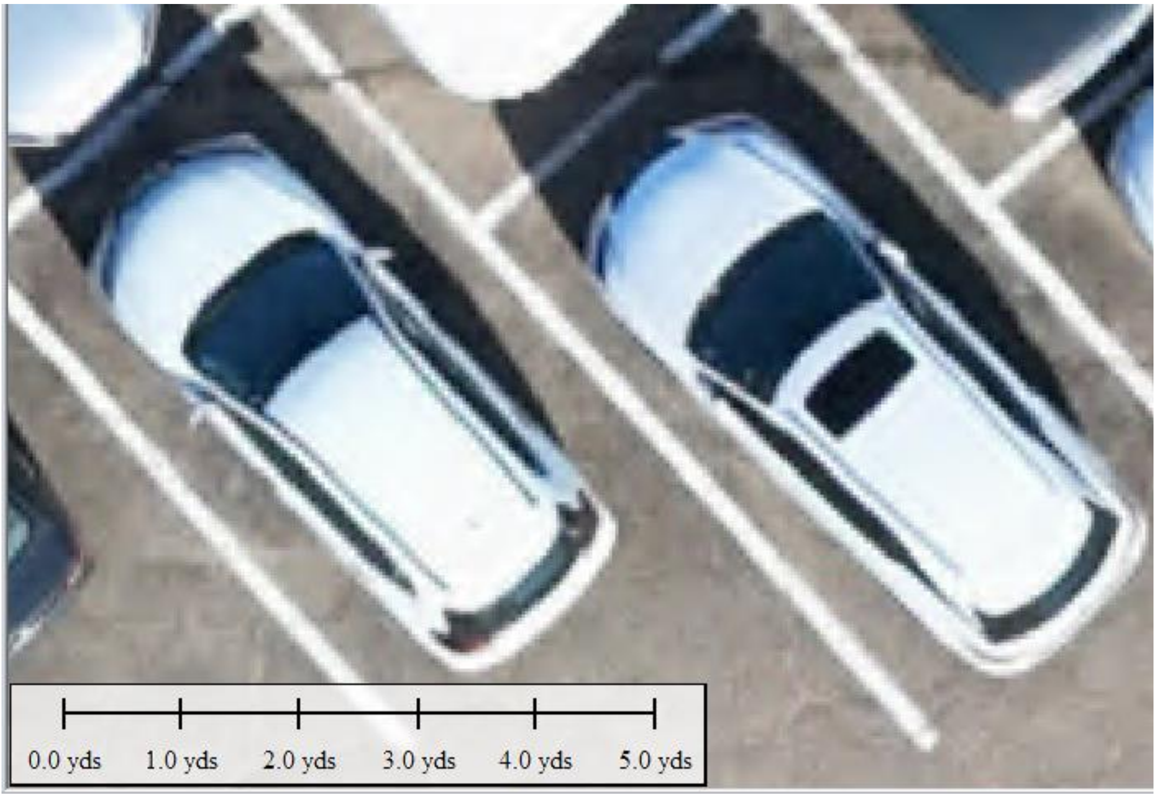
DOTD Section 30 conducted an initial LiDAR scan of the DOTD Headquarters parking lot on the morning of December 6, 2004, then performed a subsequent scan of the same area that afternoon; see Figure 9. By digitally evaluating and comparing these two scans, differences in surface conditions, features, or structural changes can be identified. In addition to surface monitoring, the scans captured detailed differences in vehicle locations within the parking lot. For example, some cars were absent in Scan I but appeared in Scan II, while others were present in Scan I but disappeared in Scan II. Certain vehicles remained stationary in shaded spots across both scans, while others showed minimal positional changes between Scan I and Scan II. Finally, some cars changed parking spots entirely, moving from one location to another (e.g., Car A to Car B). These results demonstrate how repeated LiDAR surveys can capture even subtle changes, validating the method's usefulness not only for monitoring infrastructure but also for detecting temporal variations in site use and activity.

Figure 10. DOTD HQ parking lot—Scan I, December 6, 2024, morning

Figure 11. DOTD HQ parking lot—Scan II, December 6, 2024, evening

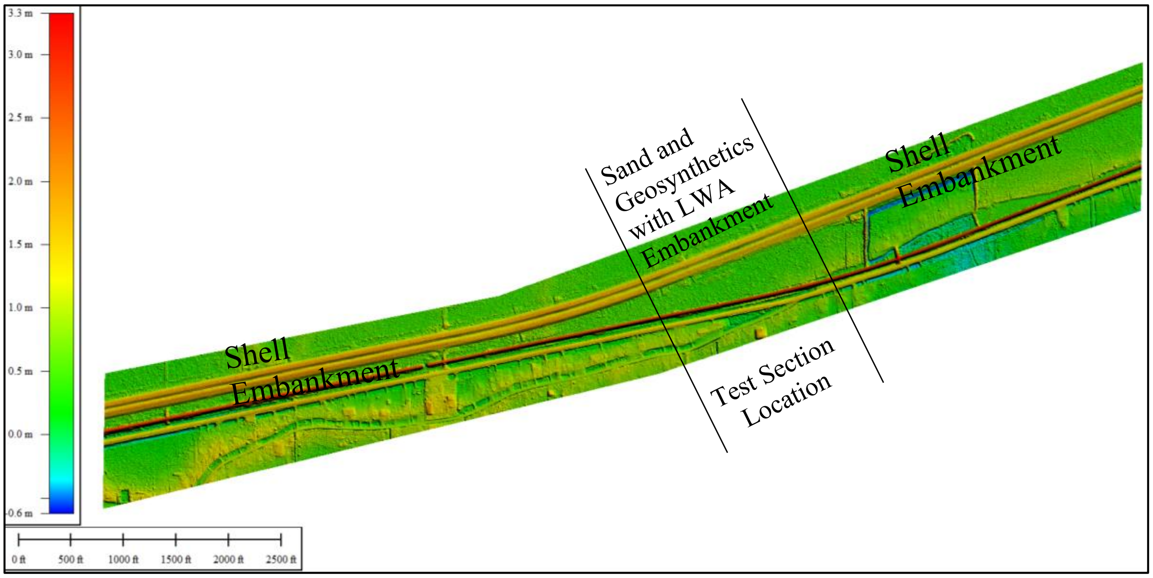
These images were created as photogrammetry images and do not contain digital elevation model (DEM) information. This prevents the calculation of volumes, as a DEM is required. The photos are georeferenced and show tremendous detail. This could be improved by accounting for the drone's height at the time of the photographs, using a more powerful lens, or choosing another technology. The level of detail for this image is shown in Figure 12, where the image becomes pixelated at a certain zoom level. Depending upon the application, this may be an acceptable level of precision.

Figure 12. DOTD HQ parking lot—level of detail



The LiDAR scan (see Figure 13) was collected on US 90, where a test section of embankment alternatives was constructed. Most of the section shown was built using oyster shell, which performed very well due to its lightweight properties, interlocking behavior, minimal settlement, and stabilizing effects. However, the use of oyster shell was eventually discontinued due to environmental concerns. In contrast, the test section constructed with sand in combination with various geosynthetics and Lightweight Aggregates (LWA) exhibited greater lateral spreading, which was evident when compared to the more vertical highway edge observed in the shell sections. Although the sand-based sections took longer to stabilize (approximately five years, compared to one year for the shell sections), the stretch ultimately showed relatively smoother surface conditions, as indicated by International Roughness Index (IRI) measurements. Despite this smoother performance, LiDAR scans also revealed evidence of global long-term settlement in the test section compared with the adjacent deep foundation bridge approaches, indicating that material choice and time continue to play critical roles in long-term stability and performance.

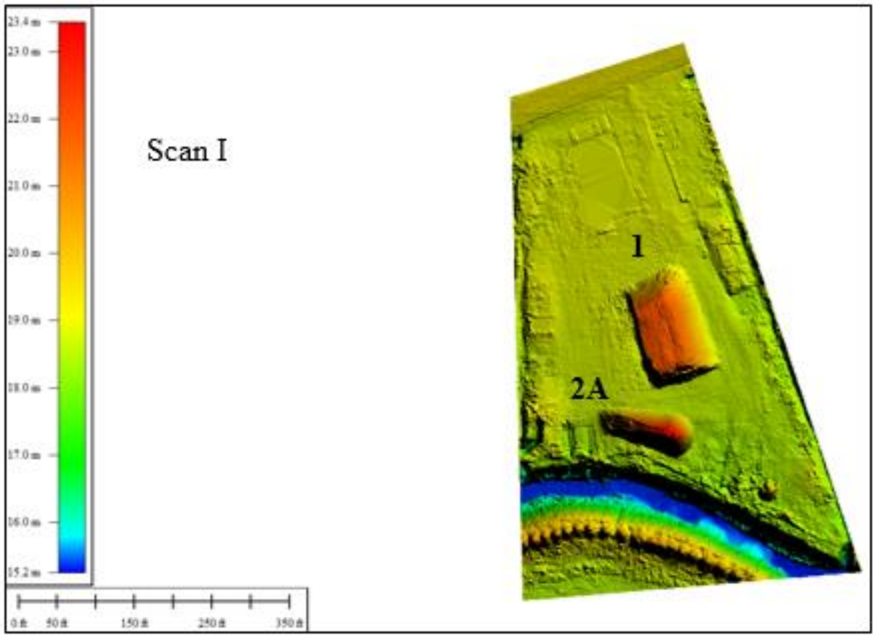
Figure 13. US 90 lightweight field test section LiDAR (December 4, 2024)



In the figure above, one can see the crisp edges of the shell embankment compared to the smoother (flatter) slopes of the sand and LWA embankment. The color of the shell areas is also darker, indicating that these sections are higher (i.e., have less total settlement).

Two LiDAR images collected from the Opelousas stockpile site document visible activity and changes over time; see Figure 14. From these scans, changes over time can be seen with the eye. The volume of the stockpiles can also be calculated by referencing the base elevation and applying standard volume calculation methods; see Table 1. This approach provides an efficient and accurate means of monitoring material quantities and site operations.

Figure 14. Opelousas, LA stockpile imagery (January 2 and May 6)



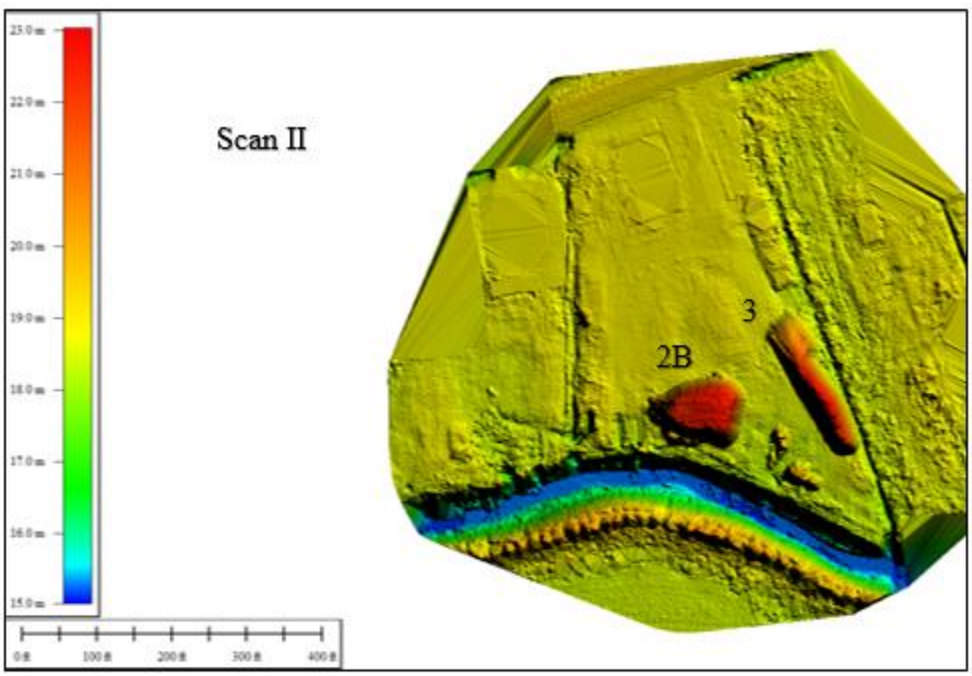


Figure 15. Areas for volume calculations

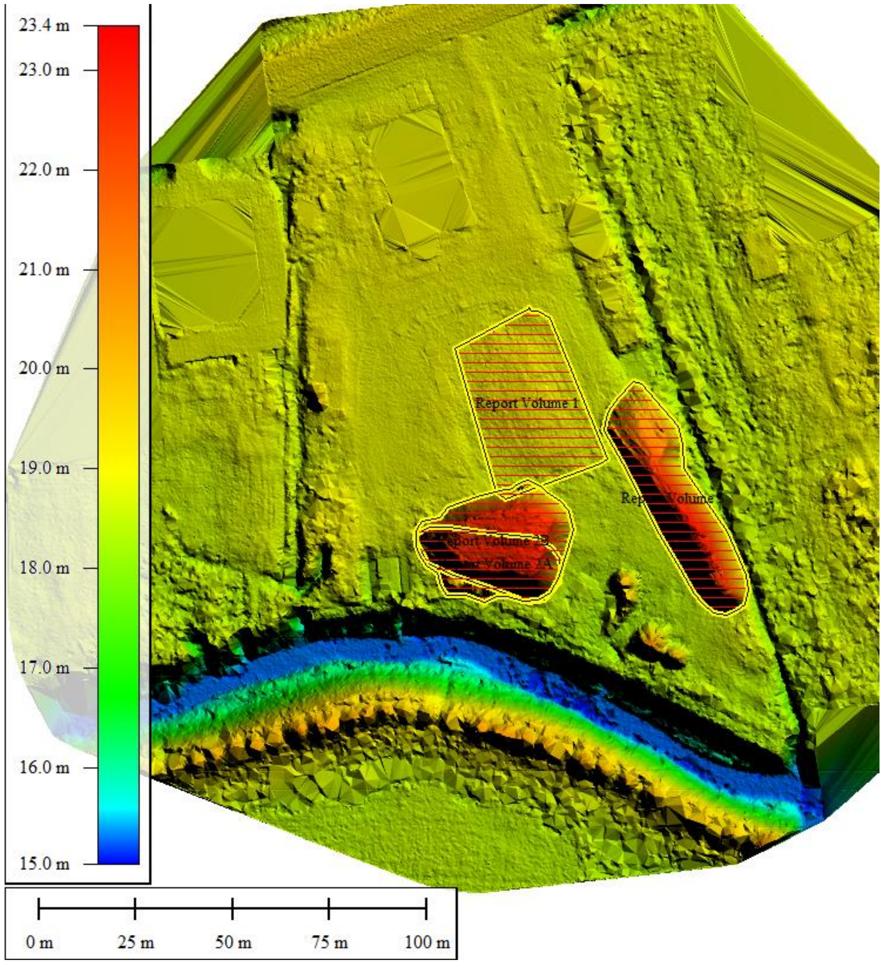


Table 1. Geometry of the Opelousas stockpiles

Pile 1 Volume (yd^3)	2730 cubic yards
Pile 2A Volume (yd^3)	1157 cubic yards
Pile 2B Volume (yd^3)	2786 cubic yards
Pile 3 Volume (yd^3)	2260 cubic yards

The east bank of the Mississippi River Bridge in Vicksburg was surveyed using LiDAR to evaluate ongoing ground movement affecting the I-20 and Railroad (RR) bridge approaches. Scan I shows the DEM, with elevations color-coded from lower elevations in blue to higher elevations in red; see Figure 16. This scan highlights the topographic relief, slope variations, and elevation changes across the site that are causing the site's instability. The orange and red areas on the right side of the data plot show some closure and triangulation errors beyond the scope of this study.

Scan II provides the corresponding orthophoto mosaic of the same area, showing surface features such as the I-20 and RR bridges, vegetation, bare earth, and access roads; see Figure 16. When considered together, the DEM (Scan I) and orthophoto (Scan II) provide both the quantitative elevation data needed for slope and settlement analyses and the contextual surface imagery necessary for interpreting features that may influence movement or block access.

Figure 17 shows additional visualizations created by Jeremy Penton of Section 30. These images show how different color options can reveal and present the slope changes with more clarity. The Vicksburg site is one of the largest natural slopes DOTD is responsible for, even though it is located on the Mississippi side of the Mississippi River.

Figure 16. Vicksburg scans (November 20, 2024)

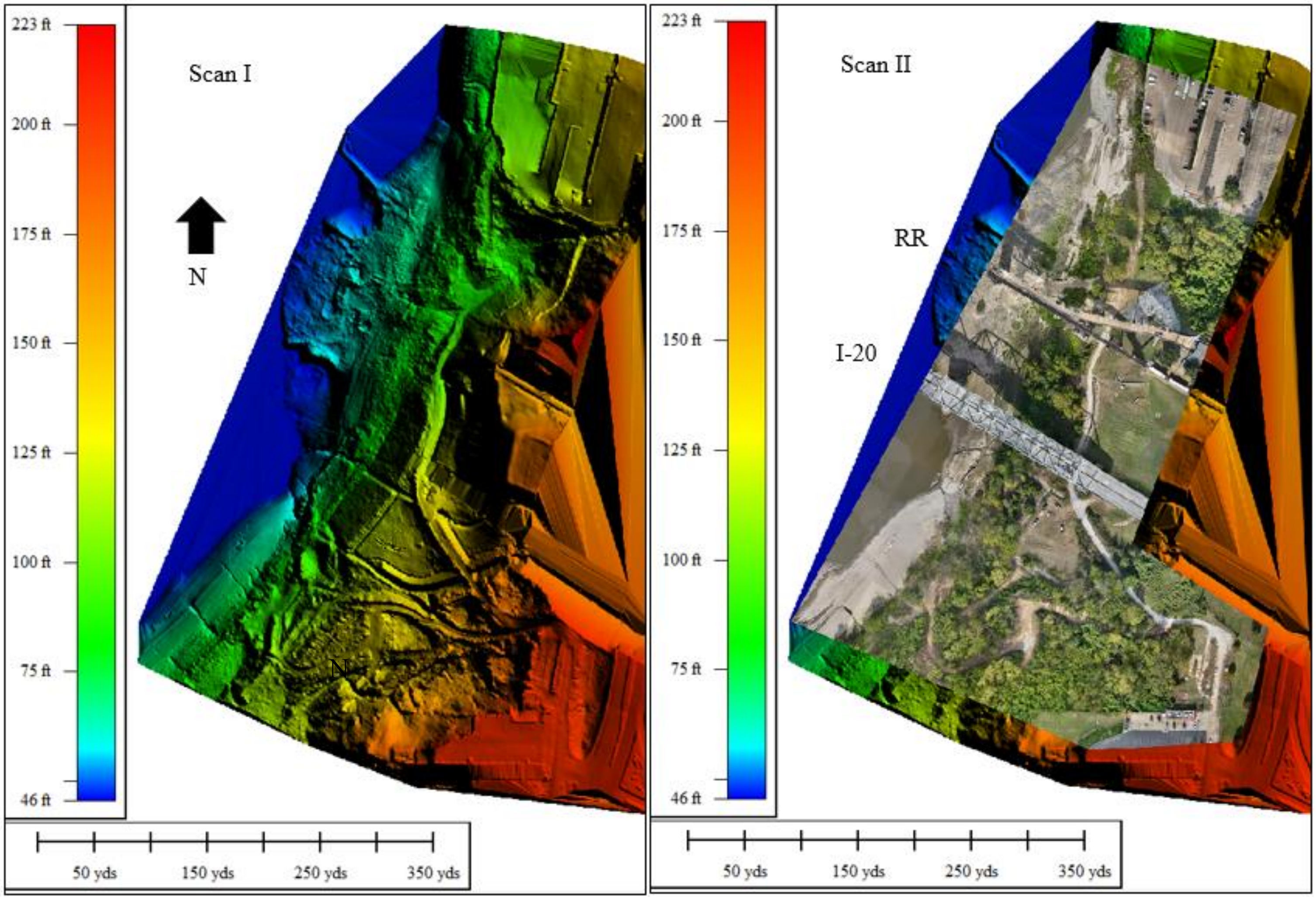
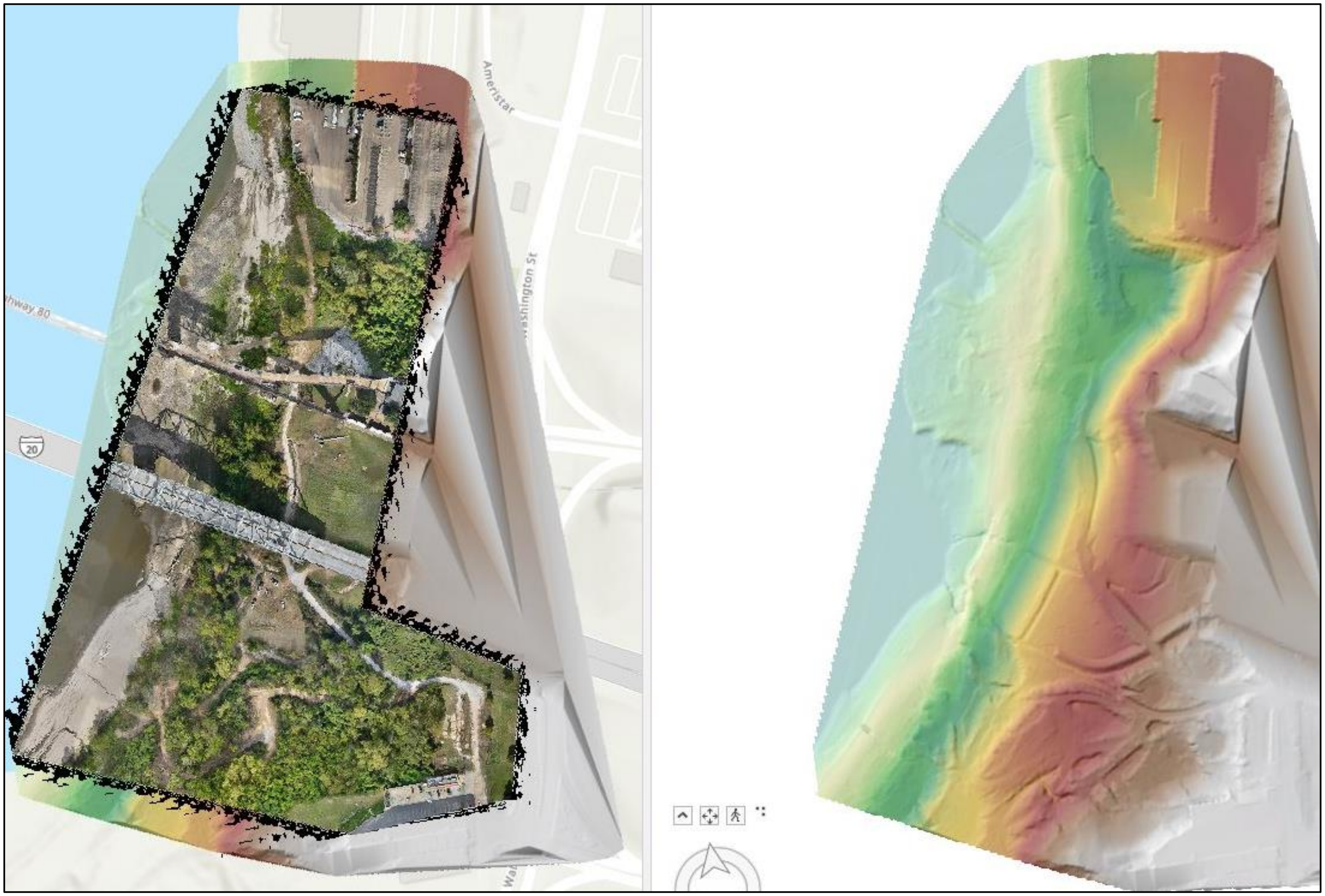


Figure 17. Other Vicksburg Bridge visualizations from Jeremy Penton

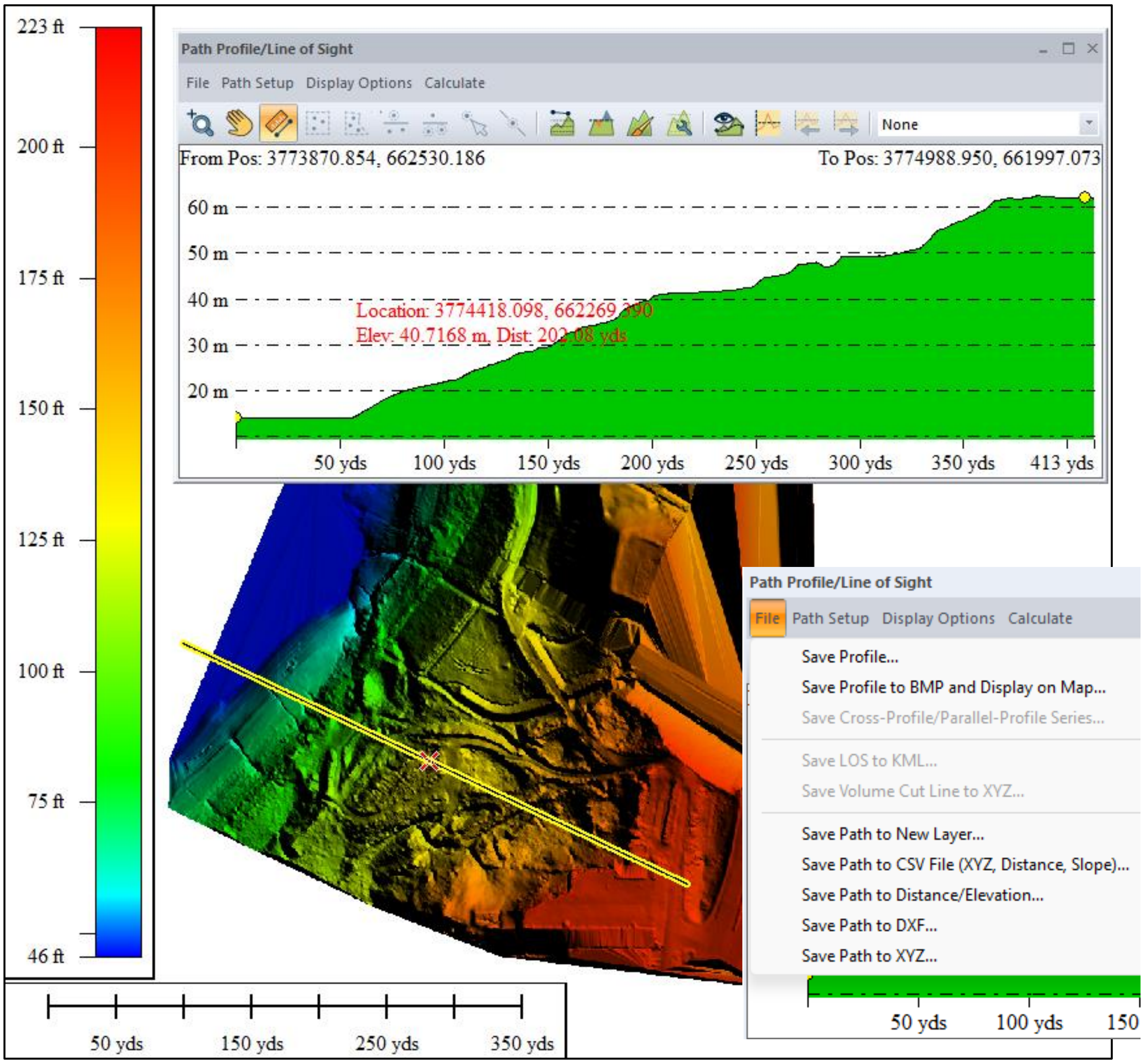


Applications

Applications of LiDAR and drone data span several critical areas, including site access evaluation, cross-section generation, change detection, slope and performance monitoring, and stockpile volume calculation. To maximize these applications, the workflow can be organized in a flowchart process: first, collect and scan the site data, then process the results to establish baseline conditions. After a set time interval, such as one month, repeat the scan and compare the new dataset to the baseline. This repeated monitoring enables systematic change detection, with defined reference points for alignment. The comparisons can then focus on multiple parameters, including scale, rate, direction, and magnitude of movement, as well as changes in volume, area, cross-sections, and speed of deformation. By structuring the workflow in this way, DOTD can ensure that LiDAR data is not only collected but also analyzed consistently over time, supporting proactive decision-making for both geotechnical and pavement projects, such as slope stability, asset performance, and material management.

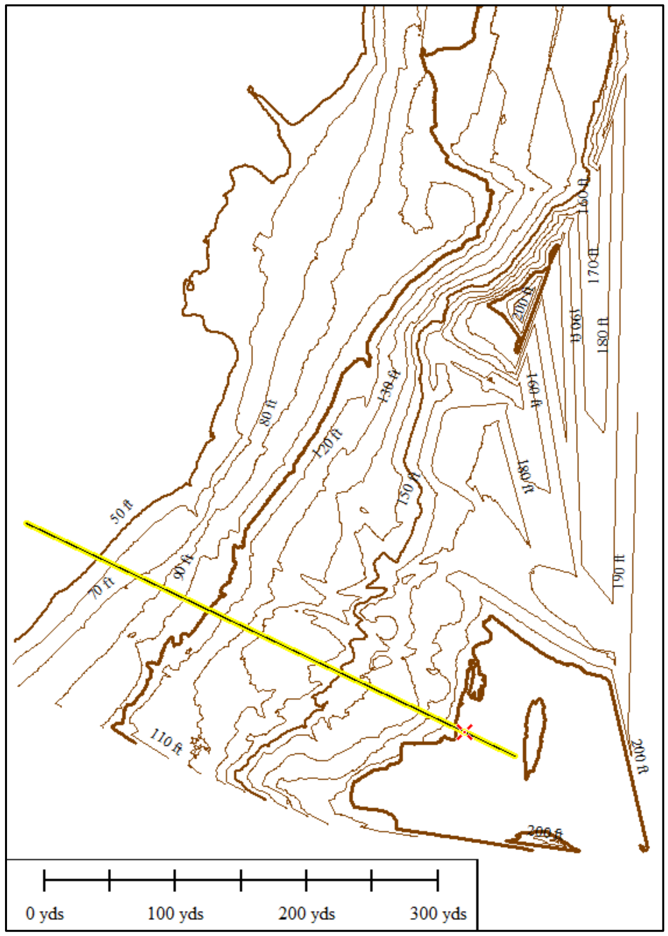
Using the Global Mapper, Path Profile Tool, a cross-section can be created from the LiDAR data; see Figure 18. The yellow line represents the section line, and the green graph shows the elevation along the yellow line to scale. The red text shows the cross-hair location and elevation. This cross-section can be saved in a variety of formats (e.g., .csv, .dxf, .xyz, etc.) and incorporated into a slope stability program. The dropdown for these options is also shown in Figure 18.

Figure 18. Cross-section created within Global Mapper from the DEM



Contours can also be created from the LiDAR data. The scale can be adjusted to meet the user's needs. See Figure 19 for an example of contour lines created from the Vicksburg Bridge DEM within Global Mapper. Site visits and analyses can be shaped by baseline data and subsequent scans to enable appropriate site access and critical analysis. The same cross-section line is shown in yellow in the contour line figure.

Figure 19. Contour lines created from the DEM



Change Detection and Slope Performance Monitoring

With more advanced analysis of LiDAR data, change detection and slope performance monitoring can be determined. This entails comparing individual pixels in separate LiDAR scans at the same point over time. The difference in the pixel elevation (z) at the same location (x & y) over time can indicate changes. When one plots all the differences, users can see the areas that rose and fell, often representing the scarp and the toe of a slope failure. These differences can be shown with heat maps to help users visualize the changes and the direction of movement. Additionally, because the scans have a time element, rates of movement can be determined. Secondary cross-sections can also be pulled and compared in 2-D.

Figure 20 shows an analysis by BGC Engineering (BGC) using their proprietary LiDAR Change Detection (LCD) software. In the figure, the heat map shows increases in elevation in red and decreases in blue. These color changes show the evolution of the stream bed and how its changes could affect the location of a bridge.

Figure 20. Using LIDAR change detection to support flooding recovery efforts in British Columbia—BGC Engineering [18]

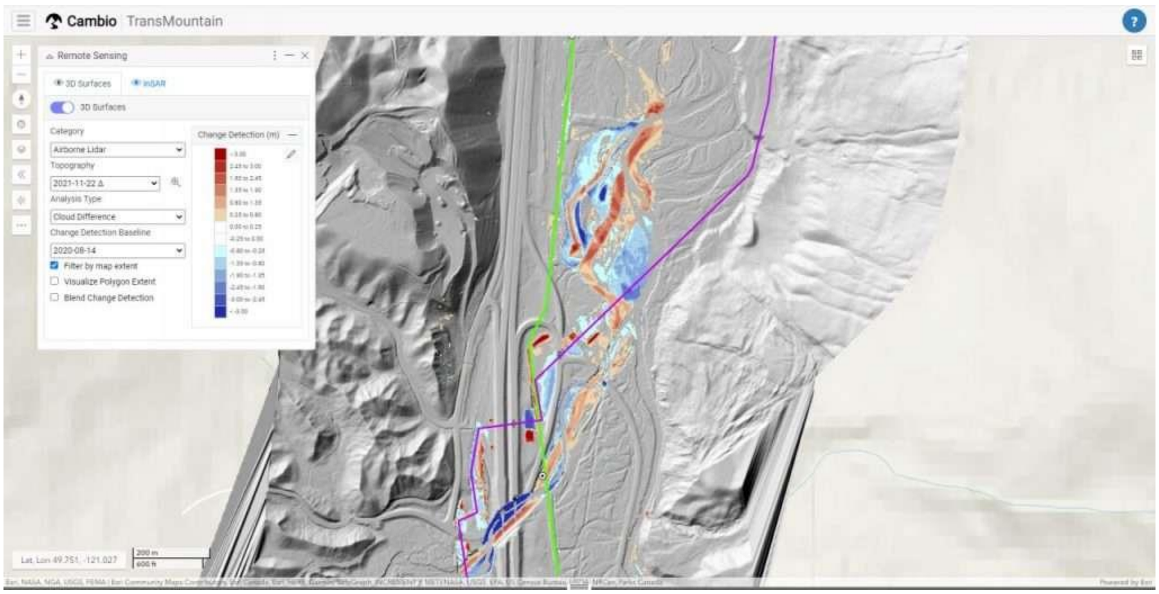
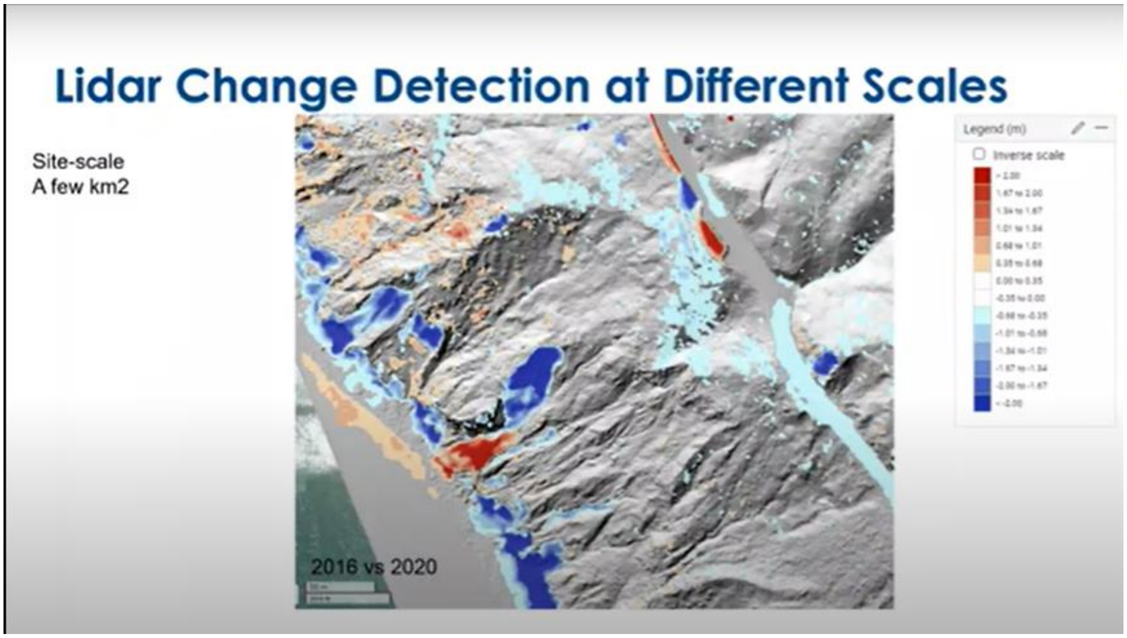


Figure 21 presents a screenshot from an informative video [19] by BGC. In the video, they show their proprietary change detection software, LiDAR Change Detection (LCD), and how it can be used to analyze different features over time.

Figure 21. BGC screenshot from video



Implementation

This research will benefit design and research efforts on geotechnical assets, the future conduct of geotechnical borings regarding access, and the evaluation of slope stability problems by utilizing existing LiDAR scans and technology for change detection, monitoring, and slope stability analyses.

The research explored and developed new tools to access and utilize LiDAR data, increasing efficiencies within Section 67, while also creating connections and inventory systems that integrate resources and assets across the Department. This data and framework can provide valuable cross-section information for projects such as slope stability analyses, allowing for proactive management of geotechnical risks. A critical component of implementation will involve using drones under Section 30 or LTRC to collect high-resolution LiDAR scans on demand.

Proper coordination of drone assets and LiDAR resources can be efficiently scheduled, shared, and applied by both the Geotechnical and Pavement groups, creating broader value across DOTD. Equally important will be the identification and training in appropriate software platforms to process, analyze, and visualize LiDAR data. A workflow can ensure that outputs are compatible with slope stability modeling tools, asset management systems, and pavement performance evaluations. Full implementation will provide DOTD with a sustainable and scalable approach to managing geotechnical and pavement assets through LiDAR-enabled decision-making.

LiDAR and Digital Survey Tools

LiDAR and digital survey tools can aid both day-to-day operations and broader agency-wide applications within DOTD. They provide Section 67 and others quick access to site-specific digital survey information, enabling efficient extraction of key information such as geometry, precision, and other relevant data for further analysis across Louisiana. Ideally, in a future effort, these resources can be incorporated and expanded into a georeferenced GIS website, where the digital dataset, including associated metadata (e.g., area of scan, date, precision, etc.), is available in a more user-friendly interface to improve access to this valuable LiDAR and geospatial information.

Conclusions

LTRC researched LiDAR resources within and beyond DOTD to compile a valuable resource for various sections within the Department to use. Though collected for specific DOTD groups, the data may benefit others, such as the Department's Geotechnical section, that did not initially request the scans. LiDAR scans and information contain information that can be used for many applications, including:

- Visualizing terrain for site access prior to traveling to the site. This can save money and time when planning and executing field excursions and testing events.
- Creating terrain maps that can be sliced into valuable cross-sectional data. This is important and can speed analysis when slope stability issues occur and remedial actions are necessary. This cross-sectional data can be extracted from LiDAR scans using software such as Global Mapper and sent directly to slope stability analysis software.
- Measuring and calculating stockpile volumes. This can also be done in Global Mapper, which helps with quantities used and needed for complete projects, as well as the associated cost calculations.
- Quantifying changes and detecting slope movement. By comparing baseline scans with other scans, pixel location changes can be quantified to assess changes at a site over time. These comparisons can give engineers insight into the rate, direction, magnitude of movements, and volume changes, helping them better adjust for immediate needs and future remedial efforts.

DOTD's Location and Survey Group, Section 30, provides excellent service and insight using drones, LiDAR, and other geospatial tools. Although they have a busy schedule, their assistance is appreciated in many ways. The addition of a LiDAR drone within LTRC for DOTD's Geotechnical unit, Section 67, could offer a faster turnaround on sites that are very active and need immediate, frequent visits to assess potential damage and the appropriate remedial response.

Recommendations

The following recommendations are provided based on the findings and conclusions of this report. They include:

- Scans conducted by Section 30 should be logged and georeferenced in an internal GIS system, so that Section 30 and other DOTD sections can see each available scan's date, precision, and area covered.
- Section 67 should communicate with Section 30 to coordinate and schedule LiDAR scans on important projects. Setting these baseline measurements could help document initial positions and locations.
- Subsequent scans should be requested for comparison and analysis against baseline conditions.
- Section 67 should install and become familiar with the functions and features of the Global Mapper software. This software is a powerful tool for visualizing information and performing calculations to support design decisions. Specifically, designers should use the software to determine:
  - Ground conditions, elevations, and contours for the initial reconnaissance of project locations, without travel, to determine site access and surface conditions.
  - Stockpile volumes and areas of construction materials or slope cut and fill volumes.
  - Cross-sectional information for the use in slope stability analyses and remedial design decisions.
  - Changes within slopes and surfaces over time by change detection processes.
  - Monitoring the long-term performance of geotechnical assets like retaining walls and embankment slopes.

The acquisition of an LTRC or Section 67 LiDAR drone is recommended for situations in which Section 30 is unavailable due to prior commitments, and for sites that have immediate geotechnical needs or require frequent visits.

Training on drone piloting and requirements is also recommended for staff to ensure sufficient crew members are available for drone missions. Additionally, backpack-mounted, tethered and/or land-based LiDAR options would expedite field collections, since piloting, permitting, and crew sizes would be eliminated or reduced.

Further studies are also recommended to assist with streamlining LiDAR technologies into modeling software such as Bentley's LeapFROG, which links to the DOTD geotechnical OpenGround database.

The research recommends expanded use of existing DOTD LiDAR datasets and the LIDAR drone through Section 30 to support projects such as slope stability analysis, geotechnical borings access, and monitoring of geotechnical assets. By integrating new software tools and analysis methods, the datasets can improve efficiency, provide valuable cross-section information, and support proactive management of slopes, pavements, and other geotechnical assets across DOTD.

Acronyms, Abbreviations, and Symbols

Term	Description
AASHTO	American Association of State Highway and Transportation Officials
ArcGIS	Geographic Information System by ESRI (ArcGIS Pro)
cm	centimeter(s)
CORS	Continuously Operating Reference Stations
CPT	Cone Penetration Testing
DEM	Digital Elevation Model
DOM	Digital Orthophoto Model
DOTD	Louisiana Department of Transportation and Development
Drone2Map	ArcGIS photogrammetry software
ESRI	GIS Software Company
FHWA	Federal Highway Administration
ft.	foot (feet)
GAM	Geotechnical Asset Management
GCP	Ground Control Point
GIS	Geographic Information System(s)
GSI	GeoStabilization International
in.	inch(es)
lb.	pound(s)
LeapFROG	Bentley 3-D Modeling Software
LiDAR	Light Detection and Ranging
LTRC	Louisiana Transportation Research Center
m	meter(s)
MDOT	Mississippi Department of Transportation
Pix4D	Drone photogrammetry software
RDR	Radio Detection and Ranging

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Appendix

Part I

Section 30: Location & Survey Uncrewed Aircraft Vehicle (UAV)

1. Purpose

The Louisiana Department of Transportation and Development has created a UAV policy that requires each Department section to further define its policy and/or procedures for the acquisition, operation, and authorized use of UAVs.

The Location and Survey section will adhere to Federal Aviation Administration 14CFR Part 107 rules, Department policy, and manufacturer recommendations regarding, but not limited to: airworthiness of the UAV, documentation of use of the UAV and tracking of time-limited parts, maintenance requirements, operation of the UAV, and the registration of the UAV.

The Location and Survey section may elect to use these systems for authorized purposes such as, but not limited to:

- Aerial photography
- Asset inspections
- Bridge inspections
- Construction area data collection
- Construction site surveillance
- Dam inspections
- Disaster response
- Drainage projects
- General mapping projects
- Incident management
- Levee inspections
- Light detection and ranging (LiDAR) collections
- Material stockpile calculations
- Public outreach
- Right-of-way and field investigations
- Thermal imaging
- Traffic monitoring
- Training exercises

Location and Survey employees are prohibited from using privately owned UAVs in the conduct of Department business or on Department time. Location and Survey employees are similarly prohibited from using DOTD-owned UAVs outside the scope of employment.

2. Procurement

Procurement of UAVs shall be in accordance with the DOTD UAV Manual, whereby the UAV shall be found on the UAV federally approved "Blue UAV Cleared List" or in compliance with the National Defense Authorization Act drone procurement guidelines. Drones not listed in the aforementioned locations will follow Department policy and require Secretary approval. All UAVs will be registered to the State of Louisiana and DOTD, and within the Location and Survey section. Additionally, the UAV specialist will report newly procured UAVs to the Aircraft Fleet Command Pilot.

3. Operation

All flights shall be documented and maintained through the DOTD–UAV Use Authorization App provided and maintained by the Location and Survey section, as well as through printed job and flight time documents to track jobs, weather, UAV system, and various other component use times. They shall also follow the Department record retention policy and schedule for documents created and utilized for equipment, pilots, and observers. In the event of inaccessibility to the DOTD–UAV Use Authorization App, physical documentation should be maintained as a substitute for DOTD–UAV Use Authorization App flight documentation.

A DOTD UAV Accident Report shall be completed by the PIC in the event of an accident or incident. A completed DOTD UAV Accident Report shall be submitted to the Aircraft Fleet Command Pilot within ten (10) business days of the accident or incident

All storage, payload guidelines, maintenance procedures, and UAV checklists will follow manufacturer-specific instructions, FAA regulations, and the DOTD UAV Manual.

All Location and Survey pilots in command (PIC) and visual observers (VO) shall be trained in accordance with FAA Part 107 regulations annually. Additionally, PIC and VO shall adhere to the manufacturer-recommended training for their UAV and its payload. Flight hours and pilot experience will be updated quarterly by each PIC and submitted annually to the Department Fleet Command Pilot.

4. Record Retention

Records shall be maintained in accordance with the Location and Survey record retention schedule. The record retention schedule can be found on the DOTD Intranet by selecting the Enterprise Support Services hyperlink under Management & Finance, Records Management, Retention Schedules, the spreadsheet titled ‘02 DOTD Retention Schedule—Section Guide’, and selecting Section 30.

5. Additional Contact Information

State of Louisiana—Department of Transportation & Development
1201 Capitol Access Road
Section 30, 2nd Floor, 204-OO
Attn: Aircraft Fleet Command Pilot
Baton Rouge, LA 70802
Office: (225) 379-1106

Part II

Louisiana Department of Transportation and Development Uncrewed Aerial Vehicle (UAV) Manual

1. Purpose

The purpose of this document is to define and outline the procurement process, personnel, training and FAA licensing requirements, operation, and reporting for the operation and usage of Uncrewed Aerial Vehicle (UAV) within the Louisiana Department of Transportation and Development (DOTD). Procedures outlined in this document regarding the operation of UAVs shall be developed, maintained, and administered by the Office of Engineering.

2. Definitions

14 CFR Part 107 (Part 107): Federal law governing the registration, pilot certification, and operation of civil small Uncrewed Aircraft systems within the United States.

AE: Associate Elements, systems, and equipment not affixed to the airframe. AE may be provided in the form of a service and may or may not use External Services (ES). Examples include, but are not limited to: Remote Pilot Station (facilities, equipment, computer devices, other hardware and software, including algorithms, interfaces, and displays); Launch and Recovery Equipment (hardware and software); command and control links (hardware and software for over-the-air transmission and data backhaul); ground-based detect and avoid (ground-based sensors, data links, hardware, and supporting software algorithms interfaces and displays).

BVLOS: Beyond Visual Line of Sight is a broad range of existing and potential UAS operations whose only common factor is that the Uncrewed Aircraft (UA) is out of the remote pilot's direct visual line of sight.

FAA: Federal Aviation Administration

Flight Plan: Documentation of mission details, including but not limited to: advance scouting via maps, UAV site, class of airspace, preliminary survey, geographic interference, man-made obstacles, and documentation of active Notice to Air Missions.

LAANC (Pronounced "Lance"): Low Altitude Authorization and Notification Capability; uses desktop and mobile apps designed to support the volume of drone operations with almost real-time airspace authorizations.

Log Book: Each section is responsible for maintaining log books and records for drone use. Each drone shall have its own independent log book, each of which is susceptible to standard record retention schedules and is subject to audit. Log books contain all pertinent information for flight, including but not limited to: time/date of flight, description of flight conditions, objectives, inspection findings, Pilot in Command and Visual Observer names, weather conditions, known hazards or obstacles, landing areas, mission limitations, and return to home flight profile.

Microweather: Specialized weather data provided for low-altitude operation of UAV.

NOTAM: Notice to Air Missions; a notice containing information essential to personnel concerned with flight operations but not known far enough in advance to be publicized by other means.

PIC: Pilot in Command

UAV: Uncrewed Aircraft Vehicle; for the purpose of this manual, UAV includes small uncrewed aircraft systems (sUAS), uncrewed aircraft (UA), and uncrewed aircraft systems (UAS).

VFR: Visual Flight Rules

VO: Visual Observer

VLOS: Visual line-of-sight

3. Personnel

Aircraft Fleet Command Pilot: Maintains a list of authorized DOTD pilots with valid annual FAA certifications, as well as DOTD-owned UAVs and associated FAA identification numbers.

Pilot in Command (PIC): Remote Pilot whose duties include: operational control of the UAV and administrative responsibilities, operation in accordance with appropriate section developed flight manuals, FAA regulations, and Department policies. Responsible for maintaining current section required training in addition to DOTD required annual FAA certifications and providing proof of certification to Aircraft Fleet Command Pilot. Only pilots who have completed the required FAA training, DOTD section-specific training, and are on the Aircraft Fleet Command Pilot UAV pilot list are authorized to fly.

Visual Observers: The primary duty of the Visual Observer is to maintain VLOS with the aircraft and stay in communication with the PIC during UAV operation to provide information regarding terrain, obstructions, and conflicting air traffic, and to assist in navigating the UAV to complete the assigned operation. Visual Observers must maintain the same training and certification as the PIC.

4. Procurement

Procurement of UAV is the responsibility of DOTD Section 14, Procurement, under the Office of Management & Finance. Procurement of UAVs must comply with all procurement guidelines and be approved by the DOTD Secretary.

Each UAV purchased must be on the UAV federally approved “Blue UAS Cleared List” or in compliance with the National Defense Authorization Act drone procurement guidelines.

Procurement of UAS not included on the Blue UAS Cleared List or in compliance with the National Defense Authorization Act drone procurement guidelines may be permitted in limited circumstances with written justification approved by the DOTD Secretary.

5. Record Keeping

All videos, images, or data obtained during UAV operations will be stored and maintained in accordance with the Department’s policy on records retention. Each section is responsible for establishing a record retention schedule with DOTD Records Management.

Information collected using the Department’s UAV is subject to disclosure pursuant to state and federal public records laws, subject to certain exceptions and exemptions provided by law. All public records requests for UAV data shall be reviewed and responded to by legal counsel.

All data will be stored on DOTD or OTS media in accordance with the statewide data security protocol.

6. Employee Responsibility

The safe operation of the UAV will be the responsibility of the PIC and VO. Any knowledge of hazards will be reported to the PIC immediately. All visual observers shall notify the PIC of conditions that warrant immediate termination of the flight.

Anything that could impair the alertness or judgment of a PIC or VO, including but not limited to illness, ingestion of impairing substances, exhaustion, or emotional problems, will prohibit the members from taking part in UAV operations.

DOTD requires one (1) PIC and a minimum of one (1) VO on all UAV operations.

Pilot and visual observer must maintain VLOS in accordance with FAA regulations.

Mobile device usage by PICs and VOs is restricted to the operation of UAVs and otherwise prohibited.

All DOTD-owned UAVs are commercial aircraft and shall be registered with the FAA accordingly. FAA registration is the responsibility of the individual section, and owner information shall be formatted as follows:

State of Louisiana
Department of Transportation and Development
(Responsible section address)
City, State Zip

7. Training

All pilots shall be familiar with their UAV's operating manual. PIC shall be certified and current with all DOTD and FAA requirements (FAA's Part 107 rule). Department PICs and VOs are required to complete FAA recurrent training annually.

It is the responsibility of the individual section to develop and maintain operational and training policies specific to the UAV and business needs. All operational and training policies shall include the following:

Pre-Flight Actions:

- Each section is responsible for completing and preserving the pre-flight checklist and flight plan for each flight.
- Inspection of the UAV according to the instructions contained in the manufacturer's manual.
- Any issues identified during pre-flight inspection shall be documented in the UAV log book and corrected prior to flight.
- Any issues with the UAV that cannot be immediately resolved will result in the UAV being taken out of service until the UAV is deemed operational.
- Review of emergency and contingency procedures for aircraft system failure, flight termination, divert to alternate or emergency landing site, lost link procedures, and loss of visual line of sight.

Post-Flight Actions:

- PIC will ensure shutdown and stowing procedures are performed in accordance with the manufacturer's instruction manual.
- UAV flights will be documented in the log book after each flight.
- Any issues identified during post-flight inspection shall be documented in the UAV logbook and corrected prior to further use.
- In the event of an accident or incident, the PIC shall submit the "DOTD UAV Accident Form" to the Aircraft Fleet Command Pilot in addition to any forms or reports required by an outside agency.

8. Compliance and Audit

The Department's Legal and Audit sections or Aircraft Fleet Command Pilot may conduct a review of the records of UAV use to ensure compliance and consistency with existing law, regulations, and DOTD policy. Where appropriate, recommendations will be made to ensure DOTD's UAV use is consistent with its authorities and applicable law, regulations, and policy.

Only FAA-certified pilots on the Aircraft Fleet Command Pilot's list are authorized to operate UAVs. A section's authority to operate a particular UAV may be revoked by Aircraft Fleet Command Pilot. An individual's ability to operate a UAV as a PIC may be revoked by Aircraft Fleet Command Pilot.

Part III

Leveraging In-House Data and External Platforms (ATLAS and Public Sources) for Database Expansion

To support DOTD's expanding need for comprehensive, multi-source information during site characterization, design, and project delivery, a consolidated catalog of reliable data platforms has been introduced. These resources span LiDAR and elevation datasets, satellite imagery, UAV and remote sensing hubs, and specialized geotechnical data repositories used locally, nationally, and internationally. Together, they provide a robust foundation for evaluating topography, subsurface conditions, surface change, environmental context, and historical project information. By organizing these platforms in a single reference list, DOTD engineers and consultants can quickly identify the most appropriate data source for preliminary assessments, advanced analyses, and cross-disciplinary coordination. This collection ensures that project teams have consistent access to high-quality spatial and geotechnical data, enhancing accuracy, efficiency, and informed decision-making across all stages of DOTD projects.

Available Geospatial Data Sources and Tools

Source Name	Website
Airbus Defense & Space	https://www.airbusus.com/
Atlas Louisiana GIS	https://www.lario.us/
BGC Engineering	https://www.bgcengineering.ca/
BoreDM	https://boredm.com/
Copernicus Land Cover	https://land.copernicus.eu/
DesignSafe-CI (NHERI Data Depot)	https://www.designsafe-ci.org/
DigitalGlobe / Maxar/Vantor	https://vantor.com/?utm_source=COMM&utm_medium=paid_search&gclid=Cj0KCQjw9-PNBhDfARIsABHN6-140FFXQdR7c-kC8sbvUFp_d6u81SfsYRduZulUfbMpFIYD9faKTRQaAjviEALw_wcB
Earthdata (NASA)	https://search.earthdata.nasa.gov/search
EERI	https://www.eeri.org/
Esri Imagery	https://www.esri.com

European Space Agency (ESA)	https://earth.esa.int/eogateway/
Forte & Tablada	https://forteandtablada.com/
GEER - Geotechnical Extreme Events Reconnaissance	https://www.geerassociation.org/
GeoRef	https://pubs.geoscienceworld.org/georef
Global Forest Watch	https://data.globalforestwatch.org/
Google Earth	https://earth.google.com/
HERE Maps	https://www.here.com/
IRIS / EarthScope Seismic Data	https://www.iris.edu/hq/
ISRO Bhuvan	https://bhuvan.nrsc.gov.in/
KeyLAB	https://www.keynetix.com/keylab/
LA DOTD GIS Data Portal	https://data-ladotd.opendata.arcgis.com/
Louisiana Imagery Download App	https://maps.dotd.la.gov/portal/apps/webappviewer/index.html?id=ddad9f0bc5a247bc8316899a6d49cb3e
Maxar Archive Search	https://www.maxar.com/
MRLC Consortium	https://www.mrlc.gov/tools
NASA Earthdata Search	https://www.earthdata.nasa.gov/data/tools/earthdata-gis
NASA Worldview	https://worldview.earthdata.nasa.gov/
National Geospatial-Intelligence Agency	https://www.nga.mil
NCALM	https://ncalm.cive.uh.edu/
NEON Open Data Portal	https://data.neonscience.org/data-products/explore
NEON Spatial Data & Maps	https://neon.maps.arcgis.com/home/index.html
Next Generation Liquefaction (NGL)	https://nextgenerationliquefaction.org/
NHERI Facilities List	https://www.designsafe-ci.org/facilities/
NHERI RAPID Facility	https://rapid.designsafe-ci.org/
NHERI SimCenter	https://simcenter.designsafe-ci.org/

NOAA Data Access Viewer	https://coast.noaa.gov/dataviewer/
NOAA Digital Coast	https://coast.noaa.gov/digitalcoast/
NREL GIS	https://www.nrel.gov/gis/
NSF DesignSafe	https://www.designsafe-ci.org/
OpenTopography	https://portal.opentopography.org/datasets
PEER NGA-West2 Ground Motion Database	https://ngawest2.berkeley.edu/
Planet	https://www.planet.com/
SGeMS	http://sgems.sourceforge.net/
U.S. Interagency Elevation Inventory	https://coast.noaa.gov/inventory/
U.S. Geological Survey, The National Map Viewer 2.0	https://apps.nationalmap.gov/downloader/
UNAVCO / EarthScope	https://www.unavco.org/
University GIS Laboratory	https://www.uis.edu/gis/projects/data
USACE – ERDC Geospatial Gateway	https://www.mvn.usace.army.mil/Missions/Engineering/Geospatial-Section/USACE-EGIS-Gateway/
USACE Open Data	https://geospatial-usace.opendata.arcgis.com/
USGS – 3DEP LiDAR Explorer	https://apps.nationalmap.gov/lidar-explorer/
USGS 3D Elevation Program (3DEP)	https://www.usgs.gov/3d-elevation-program
USGS EarthExplorer	https://earthexplorer.usgs.gov/
USGS Earthquake Hazards Program	https://earthquake.usgs.gov/
USGS Liquefaction Susceptibility	https://www.usgs.gov/programs/earthquake-hazards/liquefaction
USGS ShakeMap Archive	https://earthquake.usgs.gov/data/shakemap/
USGS Topographic LiDAR	https://www.usgs.gov
VITO Vision	https://www.vito.be/en