Joint CSCE Construction Specialty & CRC Conference 2025
Conférence conjointe spécialisée en construction de la SCGC et CRC-2025

Montreal, Quebec
July 28-31, 2025 / *28-31 juillet 2025*

EXPLORING THE USE OF TECHNOLOGIES FOR INSPECTION OF HIGHWAY CONSTRUCTION PROJECTS

Nguyen, Duc[1]* and Tran, Daniel [2]

[1] Hanoi University of Civil Engineering, Hanoi, Vietnam
[2] Dept. of Civil, Environmental and Architectural Engineering, University of Kansas, USA

ABSTRACT: Possessing the largest interstate highway system in the world, the United States relies on road transportation as the main propulsion of its economy. Highway infrastructure inspection is therefore critical for the federal and state governments during construction, operation, and investment decision-making. This study maps and evaluated the adoption of digital inspection technology by U.S. departments of transportation (DOTs) against five performance criteria – time savings, direct cost savings, measurement accuracy, inspector safety, and scalability/transferability. After compiling a comprehensive list of available technologies from the literature, we analyzed responses to a national survey of all 50 state DOTs. Five technology groups (i.e., geospatial, remote sensing and monitoring, mobile devices and software applications, non-destructive evaluation, and other emerging technologies) and their frequency of use were identified. The top digitally enabled inspection activities include earthwork include earthwork inspection and quantities, verifying and documenting work completed, monitoring construction progress, tracking construction materials, and collecting as-built information. Primary selection drivers are improving efficiency, promoting e-construction, and enhancing inspectors safety, while compatibility, staff training, and procurement costs remain key barriers. Deliverables include (i) a nation-wide snapshot of technology adoption, (ii) a taxonomy of five technology groups, (iii) an empirically derived decision-support checklist for DOT managers, and (iv) a research agenda for cost–benefit analysis and training. These findings support practitioners in evidence-based investment decisions for highway inspection technologies.

1. INTRODUCTION

Inspection plays an essential role in highway construction, providing quality assurance, a basis for payment, and verification of conformance to owners' specifications and contract requirements (FHWA 2004). Inspection continues through the maintenance phase; the Federal Highway Administration (FHWA) defined 'asset maintenance' as "Maintenance describes work that is performed to maintain the condition of the transportation system or to respond to specific conditions or events that restore the highway system to a functional state of operation. Maintenance is a critical component of an agencies asset management plan that is comprised of both routine and preventive maintenance" (Waidelich 2016).

Traditionally, inspection has relied on manual, error-prone procedures. Recent technological advances have produced a range of digital inspection tools-defined here as any electronic device or system that increases the efficiency or replaces traditional inspection approaches for determining condition, location, characteristics, dimensions, features, or other data needs (Maier et al. 2017).In the U.S., the National Highway System (NHS), whose length approximates 260,000 km, consists of several subsystems of roadways, including : Interstate , Principal Arterials, Strategic Highway Network, Major Strategic Highway Network Connectors, and Intermodal Connectors (Natzke et al. 2017). Though sometimes called the Federal Highways, these roads are typically built and have been maintained by state departments of transportation (DOTs) or local governments under the oversight of FHWA (Weingroff 2001).

The overarching objective of this research is to map, evaluate, and prioritise digital inspection technologies used by the 50 U.S. state DOTs during highway construction and maintenance. Specifically, we (1) quantify current adoption levels, (2) classify technologies into functional groups, (3) evaluate them against five performance criteria (time, cost, accuracy, safety, scalability), and (4) derive a decision-support checklist and research agenda. Primary users are DOT construction and asset-management divisions; secondary users include technology vendors and researchers aiming to advance national e-construction goals.

2. LITERATURE REVIEW

Digital inspection tools for highway projects can be grouped into three broad families—geospatial technologies, remote sensing and monitoring technologies, and mobile devices/software applications—supplemented by several emerging non-destructive evaluation (NDE) methods. This section synthesizes the technical foundations, typical highway-construction uses, and documented advantages and constraints of the principal systems in each family.

2.1 Geospatial technologies

Geospatial tools generate precise spatial information that underpins location-based inspection, progress verification, and quantity measurement.

Global Navigation Satellite Systems and Global Positioning System

Global Navigation Satellite Systems (GNSS) is the standard generic term for satellite navigation systems (i.e., constellation) that provide autonomous geospatial positioning anywhere on earth. The main GNSS constellations include GPS, GLONASS, Galileo, and BeiDou. These satellites provide signals from space and transmit positioning and timing data to GNSS receivers. The use of multiple satellites results in reduced delays in finding adequate ranges (Mallela et al. 2018) and can maintain the accuracy, redundancy, and availability at all times for collecting location data. If one satellite does not provide a quality position or fails to operate, GNSS receivers can pick up signals from other systems.

Global Positioning System (GPS) has been fully operational for more than two decades and has become a vital tool in the construction industry (Mallela et al. 2018; Ogaja 2011). GPS consists of up to 32 medium Earth orbit satellites in six different orbital planes. The exact number of satellites in GPS varies because older satellites are retired and replaced. Several GPS-based systems have been proposed or implemented to facilitate highway infrastructure inspection through the identification and tracking of materials on construction sites. Typically, GPS and GNSS technologies include three main segments as follows:

- ***Space segment***—This segment consists of satellites that continuously broadcast position and time data to GNSS receivers.
- ***Control segment***—This segment consists of ground stations that monitor, track, and collect satellite broadcast signals.
- ***User segment***—This segment consists of receivers, processors, and antennas allowing operators to determine the position, velocity, and time of the operator’s location.

Mallela et al. summarizes the typical use of GNSS/GPS technologies reported by state DOTs, construction contractors, and instrument developers/service providers through a series of interviews (Mallela et al. 2018). The study shows that both state DOTs and construction contractors use GNSS/GPS technologies for highway inspection during construction and for asset management.

Table 1: Typical use of GNSS/GPS for highway construction (Adapted from (Mallela et al. 2018))

Applications	Use of GNSS/GPS for highway infrastructure		
	by State DOTs	by construction companies	by instrument developers/ service providers
Topographic surveying	✓	✓	✓
Earthwork	✓	✓	✓
Paving	✓		✓
Roadway design	✓	✓	
AMG and control	✓	✓	✓
Verification	✓	✓	
As-built surveys	✓	✓	✓
Site/progress monitoring	✓	✓	
Inspection	✓	✓	
Quality assurance/quality control	✓	✓	
Asset management	✓	✓	✓

e-Ticketing

Recognized by FHWA's Every Day Counts initiative, e-Ticketing replaces paper haul tickets with digital records transmitted from suppliers to DOT databases (Dadi et al. 2020). The system improves data integrity, reduces inspectors' exposure to traffic, and enables automated reconciliation of material quantities delivered versus installed.

Robotic Total Stations (RTS)

RTS instruments combine electronic distance measurement with automatic target tracking, allowing a single operator to capture high-density, high-accuracy point data. They are frequently paired with prism-mounted drones or paving equipment to monitor alignment and cross-slope.

Geographic Information Systems (GIS)

GIS platforms store, visualize, and analyze spatially referenced inspection data—e.g., linking compaction results or bridge-deck delamination maps to specific chainages—thus supporting asset management and decision-making.

2.2 Remote sensing and monitoring technologies

Remote sensing devices acquire physical-condition data without direct contact, while embedded sensors provide continuous monitoring.

Light Detection and Ranging (LIDAR)

LiDAR, which is also considered a geospatial technology, is an optical remote sensing technology typically used for measuring the distance between a surface and the sensing units. LiDAR is effectively used to acquire X, Y, Z (three-dimensional or 3D) positions of any surface within the visual sight of the sensing unit. There are three main LiDAR applications: (1) static LiDAR (e.g., a system mounted at a single location), (2) mobile LiDAR (e.g., a system can be attached to a vehicle such as a truck or unmanned aircraft), and (3) airborne LiDAR (e.g., a system is attached a manned aircraft) (Maier et al. 2018). Table 2 shows typical project characteristics for using the different LiDAR methods.

Table 2: Project characteristics for using different LiDAR methods (Adapted from (Maier et al. 2018))

Aerial LiDAR	Mobile LiDAR	Static LiDAR
Mainline lengths > 1,300 ft	Long, rural corridors	Mainline lengths < 1,300 ft
Large areas and wide corridors	High-speed corridors	Small areas

Large bridge replacements	Corridors with high volumes	At-grade intersections
Variable terrain	Multilevel interchanges	Low-volume and low-speed roadways
Rural reconstructions	Resurfacing projects with cross-slope or super-elevation corrections	Flat terrain
Areas with limited foliage	Data collection time constraints	Small bridge replacements
		Urban resurfacing projects with drainage or cross-slope repairs
		Interstate widening

Static LiDAR collects highly accurate data but is comparatively much slower in data collection than mobile and airborne LiDAR and exposes DOT workers to more traffic and hazard risks. Both mobile and airborne LiDAR provide mapping-grade accuracy at high rates of travel. Mobile LiDAR applications involve digital highway measurement vehicles, LiDAR, inertial navigation systems, and GPS to provide measurements of elements such as pavement markings, pavement cross sections, shoulders and curbs (Ogle 2007; Olsen et al. 2013). Airborne LiDAR systems can collect data when traveling at 115 miles per hour at an elevation of about 1,640 feet (Dye Management Group 2014). It is noted that aerial LiDAR systems include airborne, helicopter, and UAS platforms. Mobile LiDAR systems include handheld and vehicle platforms. Table 3 summarizes a description of the capabilities and limitations of each of these typical types of LiDAR systems. It is noted that the recent development of airborne LiDAR involved improving data processing by using 3D point clouds. The cloud-based data processing approach has resulted in enhancing flexibility and faster turnaround times between the field and the office.

Table 3: Summary of different LiDAR systems (Adapted from *(Maier et al. 2018)*)

LiDAR Type	Description	Capabilities	Limitations
Aerial-Airplane	Sensor attached to fixed-wing aircraft at 1000 m or more above ground; co-acquired photographic images are becoming more common	• Rapid coverage over large areas • Fairly uniform sampling • Can collect other remote sensing data simultaneously	• Large footprint • Poor coverage on vertical faces • Flight logistics
Aerial-Helicopter	Sensor mounted to a helicopter flying closer to the ground	• Similar to airborne, but closer to ground	• Flight logistics may be complicated
Aerial-UAS	Lightweight sensor mounted to an unmanned aerial system; flight heights are typically less than 150 m	• Detailed information for a site • Pre-programmed flight paths • Nadir and oblique scanning are possible	• Short flying time limits to relatively small areas • Few systems are available, experimental
Mobile-Handheld	Sensor carried in hand or on a backpack frame	• Flexible system • Indoor/outdoor • Only one person required	• Slower than most other methods for large areas
Mobile-Vehicle	Sensor mounted to a vehicle and data are	• Fast coverage along highways	• Limited to navigable paths

	collected kinematically while a vehicle is in motion		• Obstructions from traffic
Static	The instrument is mounted to a tripod. Photographic images are often co-acquired; typically implemented only for smaller sites	• Highest resolution • Highest accuracy • Some flexibility • Indoor/outdoor	• Slower than other techniques • Non-uniform sampling

One of the key benefits of LiDAR technology is that its acquired data is useful for several applications. The collected data using LiDAR can also be mined for additional information to serve as suitable input for different applications. The typical uses of mobile LiDAR related to construction delivery include (Olsen et al. 2013):

- *As-built and maintenance documentation*—the data is integrated into a centralized database that is continuously updated for future planning, maintenance, and construction.
- *Pavement smoothness and quality determination*—data collected at higher resolutions can be used to evaluate pavement smoothness and quality.
- *Construction automation and quality control*—Change detection and deviation analysis software uses design models to identify deviations from LiDAR point clouds for construction quality control.
- *Performing quantity take-off*—LiDAR data is used to determine lengths, areas, or volumes of construction quantity.
- *Virtual and 3D Design*— LiDAR data can be used for clash detection by checking for intersections of proposed objects with existing objects modeled in the point cloud
- *Inspections*—LiDAR can provide overall geometric information and an overall condition assessment.

UAS Photogrammetry

Unmanned Aircraft Systems equipped with high-resolution cameras generate orthomosaics and 3-D surface models through structure-from-motion processing (Siebert and Teizer 2014). Typical applications include earthwork volume computations, progress visualization, and deck-crack mapping.

Intelligent Compaction (IC)

IC rollers integrate accelerometers, GNSS, and onboard computers to compute material stiffness in real time, allowing operators and inspectors to verify compaction uniformity and reduce re-work (Ranasinghe et al. 2023).

Embedded and attachable sensors

Accelerometers, maturity meters, strain gauges, infrared thermographs, and ground-penetrating radar (GPR) provide nondestructive, continuous or periodic measurements of concrete strength, pavement density, and subsurface anomalies.

2.3 Mobile devices and software applications

Handheld and in-cab computing devices deliver inspection data to field staff and back-office systems.

Tablet computers and smartphones

Ruggedized tablets running custom inspection apps allow inspectors to enter observations, capture geo-tagged photos, and synchronize data with enterprise databases. Push notifications and dashboards support real-time decision-making.

Handheld data collectors (HDCs)

RTK-enabled handhelds combine GNSS, barcode/RFID readers, and data-logging software, enabling inspectors to geolocate precast elements, verify tolerances, and populate as-built records.

Automated Machine Guidance (AMG) & 3-D Engineered Models (BIM)

Field inspectors increasingly rely on 3-D design models to compare constructed surfaces with design tolerances, perform deviation analyses, and document pay quantities (FHWA 2017). Iowa DOT, for example, updates its 3-D models continuously during construction so that the final model becomes the official record drawing (Reeder and Nelson 2015).

Virtual / Augmented Reality (VR/AR)

AR headsets can overlay design models onto the physical environment, assisting inspectors in identifying misalignments and omitted components (Tan et al. 2022).

RFID / Barcode tracking

Passive RFID tags and 2-D barcodes affixed to girders, rebar bundles, or material pallets automate identification, improve inventory accuracy, and streamline inspection workflows (Tripathi et al. 2022).

2.4 Non-destructive evaluation (NDE) and other emerging tools

Complementary NDE methods—ultrasonic tomography, impact-echo, acoustic emission, and laser stereography—are gaining traction for bridge-deck delamination detection and weld inspection (Gupta et al. 2022). While adoption remains limited, several state DOTs are experimenting with combined LiDAR–thermography or UAS-mounted GPR to obtain multi-modal datasets.

3. METHODOLOGY

3.1 Literature Review

A comprehensive literature review of related technologies for construction inspection was conducted. An effort was made to seek not only the most current information but also archival information so that the change over time, if any, in using technologies for construction inspection could be mapped and related to the current state of the practice. The search included current academic literature, industry publications, state DOT websites, and government reports to find the most current trends and practices in using technologies for construction inspection.

3.2 Survey design and distribution

A web-based survey was developed and distributed to the members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Construction. A total of 42 responses were received (82% response rate). Among the 42 responses, 41 state DOTs (98%) indicated that they had used mobile devices and software applications for the inspection of their highway infrastructure during the construction or maintenance of assets. Thirty-two state DOTs (76%) reported that they used geospatial technologies for highway infrastructure inspection. Similarly, two-thirds of responding state DOTs (28 responses or 67%) mentioned that they used remote sensing and monitoring technologies or non-destructive evaluation methods for the inspection of their highway infrastructure during the construction or maintenance of assets. It is important to note that the 46 state DOT respondents were not required to respond to all questions in the survey. As a result, the sample size (n) of each question varies.

3.3 Evaluation criteria and analytical procedure

Five “goodness” metrics guided both survey questions and subsequent analysis: (i) time savings, (ii) direct cost savings, (iii) measurement accuracy, (iv) inspector safety, and (v) scalability/transferability to other projects. Respondents rated each technology group on a five-point Likert scale for every metric. Descriptive statistics, cross-tabulations, and Spearman rank correlations were then calculated to explore relationships between adoption levels and performance perceptions.

4. RESULTS AND DISCUSSION

4.1 Uses of technologies across DOTs

Responses from DOTs revealed three groups of technologies in use (i.e., geospatial technologies, remote sensing and monitoring technologies, and mobile devices and software applications) along with frequencies of technologies.

Geospatial technologies

Figure 1 shows the main geospatial technologies used for highway infrastructure inspection during construction. Twenty-six state DOTs (81%) have used GNSS/GPS; 19 state DOTs (59%) have used e-Ticketing technologies; and nine state DOTs (28%) have used Terrestrial Photogrammetry (TP) for inspection of their highway infrastructure during construction. Figure 1 also indicates that approximately 50% of the 32 responding DOTs have used unmanned aircraft systems (UAS), Robotic Total Stations (RTS), and Geographic Information Systems (GIS) for inspection of their highway infrastructure during construction.

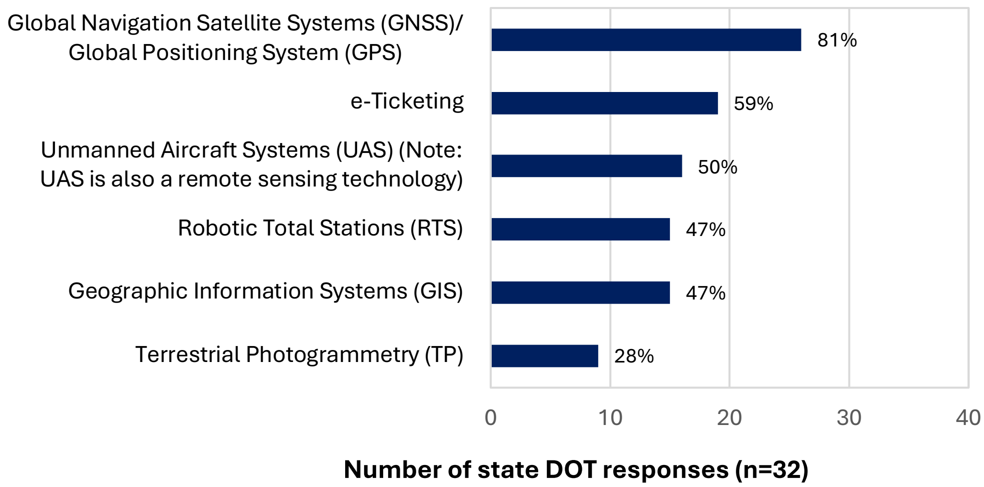

Figure 1: Types of geospatial technologies used for highway infrastructure inspection during construction

Remote sensing and monitoring technologies

Figure 2 shows the main types of remote sensing and monitoring technologies used for highway infrastructure inspection during construction. Out of 28 responses, 21 DOTs (75%) have used remote sensors (e.g., accelerometers, maturity meter sensors, or strain gauges); 15 DOTs (54%) have used remote cameras; 14 DOTs (50%) have used intelligent compaction and Light Detection and Ranging (LIDAR)/3D laser scanning; and 13 DOTs (46%) have used infrared sensors (e.g., thermal, motion detectors, object detection, thermal profiling) for inspection of their highway infrastructure during construction. Figure 2 also indicates that four DOTs (14%) have used barcodes and readers and three DOTs (11%) have used radio-frequency identification (RFID) for the inspection of their highway infrastructure during construction.

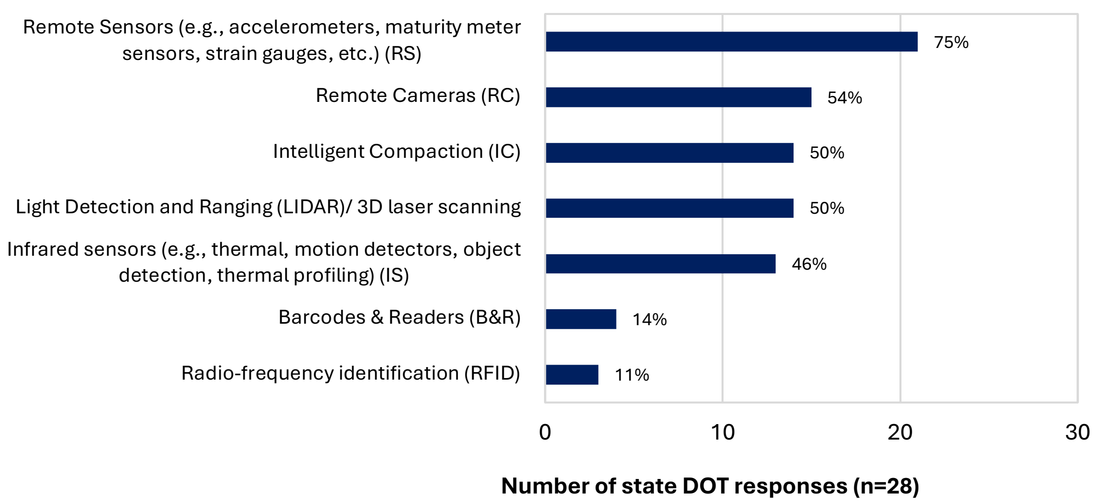

Figure 2: Types of remote sensing and monitoring technologies used for highway infrastructure inspection during construction

Mobile devices and software applications

Figure 3 indicates the typical mobile devices and software applications that DOTs use for highway infrastructure inspection during construction. Out of 41 responses, 37 DOTs (90%) have used tablet computers and smartphones (TSs); 22 DOTs (54%) have used handheld data collectors (HDCs) such as Real-time Kinematics (RTK) or Trimble Yuma; and 17 DOTs (41%) have used Automated Machine Guidance (AMG) and 3D Engineered Models/BIM (3D models) for inspection of their highway infrastructure during construction. Figure 3 also indicates that two DOTs (California and Connecticut) have used Virtual Reality/Augmented Reality (VR/AR) for the inspection of their highway infrastructure during construction.

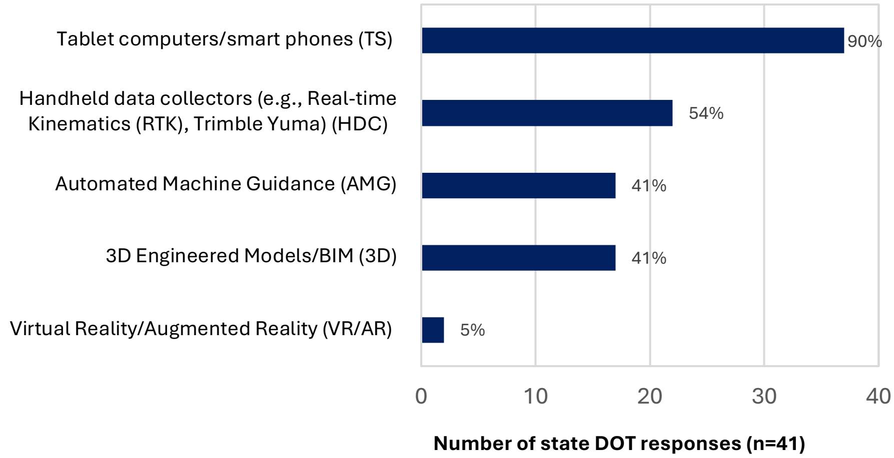

Figure 3: Types of mobile devices and software applications used for highway infrastructure inspection during construction

4.2 Applications of technologies in construction inspection

These technologies have a wide range of applications in the construction inspection of highways (Table 4). Geospatial technologies have been used most frequently among the three technologies. Some applications such as earthwork inspection and quantities, collecting as-built information/developing 3D as-built models, and quality control and quality assurance activities have utilized all types of technologies.

Table 4: Applications of technologies by DOTs

Applications	Geospatial technologies	Remote sensing and monitoring technologies	Mobile devices and software applications
Earthwork inspection and quantities	✓	✓	✓
Collecting as-built information/Developing 3D as-built models	✓	✓	✓
Site photos and videos	✓		
Monitoring construction progress	✓		✓
Locating underground utilities and underground assets	✓		
Quality control and quality assurance activities	✓	✓	✓
Verification and documentation of work completed for payment	✓		✓
Structural inspection and quantities	✓	✓	
Measurement of material strength and temperature		✓	
Measurement of pavement thickness		✓	

4.3 Challenges in implementation of technologies

The implementation of technologies has faced similar challenges.

Table 5 summarizes most common challenges, including cost issues, lack of training, knowledge and skills, and user support. The convergence of challenges suggests efficient adopting strategies for state practitioners in overcoming difficulties in the implementation of technologies.

Table 5: Challenges in implementation of technologies in construction inspection

Challenges in implementation	Geospatial technologies (32 DOTs)	Remote sensing and monitoring technologies (28 DOTs)	Mobile devices and software applications (32 DOTs)
Lack of training, knowledge, and skills to use technologies	✓	✓	✓
Lack of reliable internet connection in remote locations	✓	✓	✓
Cost issues	✓	✓	✓
Lack of standard contract specifications	✓	✓	
Device maintenance and user support	✓	✓	✓
Resistance to change			✓

4.4 Drivers for selecting the technologies for highway inspection

Figure 4 shows the primary drivers for selecting the technologies for highway inspection based on the responses from 42 state DOTs.

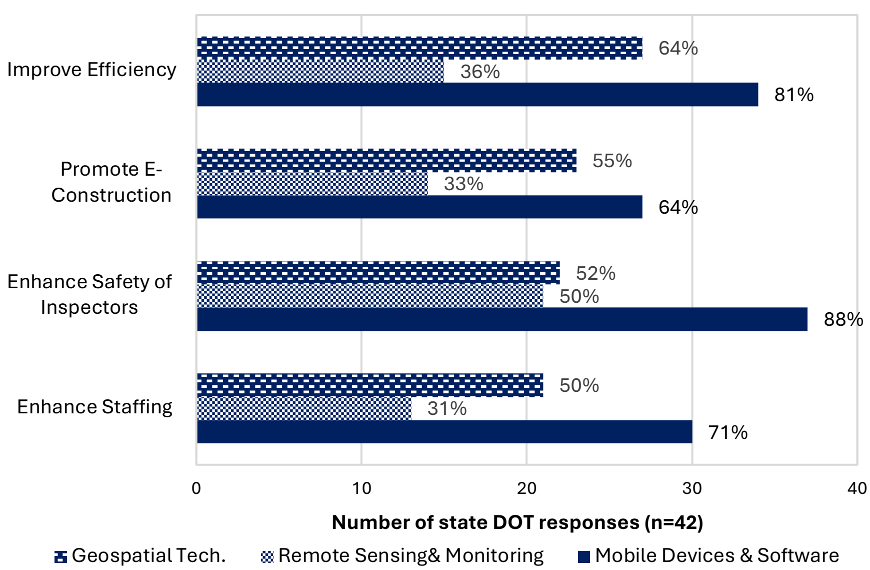

Figure 4: Primary drivers for selecting technologies for highway inspection

Figure 4 indicates that more than 70% of the 42 responding DOTs indicated that the main driving factors for using mobile devices and software applications are to (1) enhance the safety of inspectors; (2) improve efficiency; and (3) enhance staffing (e.g., using mobile devices and software applications reduces the need of inspection staff). Similarly, more than half of 42 DOT responded that the main driving factors of using geospatial technologies are to (1) improve efficiency; (2) promote e-Construction; and (3) enhance the safety of inspectors. Figure 4 also indicates that the main driver of using remote sensing and monitoring technologies and nondestructive evaluation methods is to enhance the safety of inspectors.

5. CONCLUSION

This study investigates the state of practice by state DOTs for using various technologies to inspect highway infrastructure during the construction and maintenance of assets. First, a synthesis of various technologies was obtained through a comprehensive literature review. Then, a survey was conducted in the 50 states in the U.S. to identify technologies used by DOTs for inspection of new and existing highway infrastructure assets, to document methods used to assess the viabilities and efficiencies of those technologies and to identify how information obtained was used for the DOTs' management purposes.

This study examined three main groups of digital technologies used in highway infrastructure inspection: (1) geospatial technologies, (2) remote monitoring and sensing technologies, and (3) mobile devices and software application technologies. Out of 42 responses, 32 state DOTs have used geospatial technologies; 28 state DOTs have used remote sensing and monitoring technologies; 41 state DOTs have used mobile devices and software applications; and 28 state DOTs have used non-destructive evaluation methods. In addition, more than 70% of the 42 responding state DOTs have used mobile devices and software application for inspection of various infrastructure types including roadways, signage and roadside, bridges, earthwork and grading, drainage systems, and non-bridge structures.

Though there exist challenges, such as lack of training, cost issues, lack of standard contract specifications, and device maintenance and user support, digital technologies are critical and have improved the performance of highway infrastructure inspection. DOTs have used performance metrics to evaluate the use of technologies in the inspection. The most frequent metrics are efficiencies gained, increase in quality, overcoming limited inspection resources, cost-benefit analysis, end-user approval, and advancement in technology.

There are several limitations in this study that warrant future research. For example, to promote the effective use of technologies for the inspection of highway infrastructure during the construction and maintenance of assets, future research is suggested in the following areas: (1) developing a framework to empirically investigate the relationships between inspection technologies and the allocation of inspection resources during construction and asset management; (2) developing guidance on conducting the benefit–cost analysis and empirically derived calculation of return on investment of inspection technologies for highway infrastructure. The guidance could include assessments of the value of using technologies for inspections compared with traditional inspection methods; and (3) investigating how to gain buy-in from users and leadership to develop effective training methods as well as core skill sets and competence for inspectors in the use of various inspection technologies during construction and asset management.

ACKNOWLEDGMENTS

The authors acknowledge and appreciate the information provided by the staff members of the numerous State Departments of Transportation who assisted with this study.

REFERENCES

Dadi, G. B., R. Sturgill, D. Patel, C. Van Dyke, and G. Mulder. 2020. *NCHRP Synthesis 545: Electronic Ticketing of Materials for Construction Management*. Washington, D.C.

Dye Management Group, I. 2014. "Monitoring Highway Assets with Remote Technology." *Michigan Department of Transportation*, (OR10-030).

Federal Highway Administration. 2004. *Construction Program Management and Inspection Guide*.

Federal Highway Administration (FHWA). 2017. *EDC-3 Final Report*.

Gupta, M., M. A. Khan, R. Butola, and R. M. Singari. 2022. "Advances in applications of Non-Destructive Testing (NDT): A review." *Advances in Materials and Processing Technologies*, 8 (2). https://doi.org/10.1080/2374068X.2021.1909332.

Maier, F., L. E. Chummers, S. Pulikanti, J. Q. Struthers, J. Mallela, R. H. Morgan, and U. States. F. H. Administration. O. of I. R. and Development. 2017. "Utilizing 3D Digital Design Data in Highway Construction - Case Studies." United States. Federal Highway Administration. Office of Infrastructure Research and Development. https://doi.org/10.21949/1503647.

Maier, F., J. Mallela, H. N. Torres, J. M. Ruiz, G. K. Chang, P. Brinckerhoff, and Inc. The Transtec Group. 2018. “Automation in Highway Construction Part II: Design Guidance and Guide Specification Manual.” United States. Federal Highway Administration. https://doi.org/10.21949/1503647.

Mallela, J., A. Mitchell, J. Gustafson, M. J. Olsen, C. Parrish, D. T. Gillins, M. Kumpula, G. Roe, and D. and T. United States. Federal Highway Administration. Office of Research. 2018. “Effective Use of Geospatial Tools in Highway Construction.” United States. Federal Highway Administration. Office of Research, Development, and Technology. https://doi.org/10.21949/1503647.

Natzke, S., M. Neathery, and E. Starks. 2017. *What is the National Highway System?*

Ogaja, C. A. 2011. *Applied GPS for engineers and project managers*. *Applied GPS for Engineers and Project Managers*.

Ogle, J. 2007. *NCHRP Synthesis 367: Technologies for Improving Safety Data*. Washington, D.C.

Olsen, M. J., G. v. Roe, C. Glennie, F. Persi, P. Consulting, M. Reedy, D. Evans, D. Hurwitz, K. Williams, H. Tuss, P. Consulting Marcus Reedy, D. Evans, A. David Hurwitz, K. Williams, A. Squellati, A. Mike Knodler, G. v. Roe, C. Glennie, F. Persi, P. Consulting, M. Reedy, D. Evans, D. Hurwitz, K. Williams, H. Tuss, and M. Knodler. 2013. “Guidelines for the Use of Mobile Lidar in Transportation Applications Final Guidelines.” *Transportation Research*, (February 2013).

Ranasinghe, R., A. Sounthararajah, and J. Kodikara. 2023. “An Intelligent Compaction Analyzer: A Versatile Platform for Real-Time Recording, Monitoring, and Analyzing of Road Material Compaction.” *Sensors*, 23 (17). https://doi.org/10.3390/s23177507.

Reeder, G. D., and G. A. Nelson. 2015. *Implementation Manual 3D Engineered Models for Highway Construction: The Iowa Experience*.

Siebert, S., and J. Teizer. 2014. “Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system.” *Autom Constr*, 41. https://doi.org/10.1016/j.autcon.2014.01.004.

Tan, Y., W. Xu, S. Li, and K. Chen. 2022. “Augmented and Virtual Reality (AR/VR) for Education and Training in the AEC Industry: A Systematic Review of Research and Applications.” *Buildings*.

Tripathi, A., H. Nassereddine, G. Dadi, and R. E. Sturgill. 2022. “Toward a Readiness Assessment for Wireless Technologies for Highway Construction and Infrastructure Asset Management.” *Construction Research Congress 2022: Computer Applications, Automation, and Data Analytics - Selected Papers from Construction Research Congress 2022*.

Waidelich, W. C. 2016. *Memorandum: Guidance on Highway Preservation and Maintenance*.

Weingroff, R. F. 2001. *From Names to Numbers: The Origins of the U.S. Numbered Highway System*. Washington D.C.