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Inspection in the Field: An Overview of the Current State of Practice of Mobile Devices in State Departments of Transportation

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***Abstract*— Existing and emerging digital technologies are transforming State Departments of Transportation (DOTs) to design, plan, construct, inspect, maintain, and document construction projects. With the advancements of smartphones, tablets and peripheral devices are increasingly used as innovative tools in construction project delivery, specifically in field inspection and documentation.**

The paper outlines an overview of the ongoing practice of mobile devices as a tool for Project Documentation and Inspection. An online survey was distributed to state DOT representatives regarding the practices for using mobile devices to support digitized project documentation and inspection. The responses were received concerning the current state of practice of mobile devices (e.g., level of personnel issued mobile devices within the agency, administration of mobile devices), cost implications for using mobile devices (e.g., software licenses, capital replacement); and challenges and barriers (e.g., connectivity, mobile device management) correlated with using mobile devices for inspection.

The finding shows the current state of mobile device usage among those states and also acts as a guidance and strategy for other state DOTs continuing to invest in using mobile devices for inspection and documentation.

***Index Terms*— Digital Project Delivery, Mobile device Applications, Mobile usage policy, Inspection.**

I. INTRODUCTION

Construction projects are becoming more complicated and demanding to manage due to the interdependence of various stakeholders. The site management process is still influenced by paper-based records, causing increased costs, errors, and waste for construction companies, and significant time on construction sites is devoted to performing non-value activities, increasing the waste and rates of inefficiency [1]. Recently, mobile devices have been widely introduced at construction sites as an alternative way to capture site data. Some construction companies are developing their mobile applications because the volume of information produced is so large it needs to be managed more efficiently [2].

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In a 2022 survey of State Departments of Transportation (DOTs) in the 50 states and the District of Columbia, where the survey questionnaire was distributed to the members of the AASHTO Committee on Construction (COC), of which 42 state DOTs submitted a survey response (an 82% response rate). Results showed that tablets and smartphones are the most dominant mobile devices used by the 41 state DOTs that reported use of mobile devices for inspection of highway infrastructure during construction (90% of the 41 DOT responses) and maintenance of assets (39% of the 41 DOT responses)[3]. The top inspection activities using tablets and smartphones during construction, collected from the survey and case examples[3], include verifying and documenting work completed for payment, monitoring construction progress, and capturing site photos and videos. Mobile devices and software applications allow state DOTs to improve the process of collecting, documenting, and distributing project inspection information. Eight state DOTs (Florida, Illinois, Iowa, Minnesota, New York, Oregon, Pennsylvania, and South Dakota) reported substantial use of mobile devices and software applications for highway construction inspection and asset management. The majority of mobile devices are used for the assessment of infrastructure. The top inspection activities that utilize tablets and smartphones during highway construction include verification and documentation of work completed for payment, monitoring construction progress, and capturing site photos and videos[3]. Data collection costs increase significantly when sophisticated devices are used to collect data to address contemporary transportation issues. Due to this constraint, state DOTs struggle to collect consistent data for analysing and resolving transportation problems on time[4].

Despite the numerous benefits of using mobile devices for inspection purposes, challenges include the need for a significant initial investment and the training of workers on using this technology[5]. Barriers include resistance to change and hesitancy in adopting new technology[6]. Experts highlighted other challenges, such as the need for more collaboration across the industry, the affordability of technology, and the lack of expertise. The top challenges in using mobile devices and software applications for highway infrastructure inspection during construction or maintenance of assets include lack of reliable internet connection in remote locations; lack of training, knowledge, and skills to use technologies; cost issues; device maintenance and user support; and resistance to change[5]. Other implementation barriers are poor information exchange, a sizeable initial investment, unawareness of the benefits of mobile devices, and complexity of the software. These patterns were categorized into people, technology, and process, and have been named the three critical drivers for boosting the adoption of onsite digital tools. People are the main drivers and the most crucial. Companies have many options to motivate people to utilize the new technology, from enhancing the existing training scheme to imposing these tools[2].

The study presented here is part of an overarching objective of investigating information related to the current practices of DOTs using mobile devices to perform their work, inspection functions, and mobile device applications that can be utilized by construction professionals. Some of the mobile device applications include digitalized documents, geolocation of data, augmented reality with engineering precession, capturing 3D images of as-built conditions through built-in LiDAR cameras, object recognition through AI, viewing of 3-D models, access to inspection history, connecting quality assurance results to the model, and improved communications. Also, this research aims to highlight information related to the policies and practices regarding using personal and/or DOT-issued mobile devices. Furthermore, cost implications for using mobile devices and the barriers and challenges for their use that DOTs encounter are identified, which can lead to improved efficiency, reduced costs, and move into a more digital-based delivery.

II. BACKGROUND

Mobile devices were first inaugurated at construction sites in the 1990s but could only perform basic functions. With the development of the iPad and similar devices, construction technologies have increased enormously[7]. Some of the larger construction companies in the United States provide their project managers and superintendents with mobile devices to perform construction operations. Construction companies in the U.S. which has less than $250 million in revenue provide capital for about 1.6% of it on information technology (IT); on the other hand, companies with $10 billion in revenue only spend 1.1%[8]. These levels of spending on IT-related resources indicate that construction companies are making significant investments in the IT area with the intention of using mobile devices in their day-to-day operations.

From a project management standpoint, mobile technology has vastly changed how companies oversee projects. A considerable amount of research has been done regarding the use of mobile technology to assist the construction industry fieldwork. For example, scrutinizing the information needs of on-site personnel and listed different considerations when selecting the hardware, software, and network infrastructure for construction

sites[9]. Employing mobile technology at the point of activity can reduce construction time, cost, defects, accidents, and waste while improving predictability and productivity[9].
In the construction stage, mobile/cloud BIM technology helps with tracking progress, scheduling coordination of construction, eliminating clashes due to design mistakes, and facilitating the remote interchange of data wirelessly through the Internet[10]. Furthermore, mobile BIM technology is a way to enable higher levels of cooperation and collaboration, providing a more effective platform for virtual communication among project participants[11]. With the introduction of mobile devices and their accompanying collaboration technologies, companies can now collaborate with all the relevant parties in real-time, wherever they are on the work site[12]. The mobile solution supports electronic data collection and information exchange for construction industry fieldwork. Collecting and accessing accurate, up-to-date information with mobile devices at the worksite and sharing the information with project partners in real-time, as well as the proposed addition of offline functionality, the utilization of mobile phones with integrated RFID and GPS functionalities should be researched further[13].

A. Different approaches adopted by state DOTs for construction documentation and inspection

e-Construction has piqued national interest because of its many benefits. State DOTs are realizing time and cost savings, enhanced quality, and improved data availability from e-construction. States are mainstreaming many e-construction system practices and showing significant returns on investment. Through enhanced awareness and promotion of benefits and examples of e-Construction application, the highway industry is ready to reap the benefits of program-level implementation. Recognizing the significant potential benefits to States, FHWA included e-Construction in its third and fourth rounds of Every Day Counts (EDC). In EDC-3 (2015–2016), FHWA promoted this innovation and encouraged the use of readily available technologies, including digital and electronic signatures, electronic communication, secure file sharing, mobile devices, and Web-hosted data archival and retrieval systems. In the fourth round of EDC (2017–2018), FHWA is promoting e-construction with a focus on enhancing Construction Partnering among stakeholders while improving communication and workflow to streamline the delivery of projects. In addition to these efforts, FHWA led and completed a research project on e-construction to collect detailed benefit and cost data. FHWA created a benefit-cost analysis template from this research to capture cost data using the varying e-construction tools over a 7-year period. According to this research, the documented 7-year return on investment for construction management, project collaboration, mobile devices, and electronic bidding tools ranges from 200 to more than 700 percent. Time savings with e-Construction have averaged 1.78 hours per day per inspector, and inspectors have collected up to 2.75 times more data. In addition, DOTs have reported cost savings of up to $40,000 per construction project per year. FHWA division offices work closely with their State DOT counterparts, which presents an opportunity to provide seamless project delivery and enable electronic integration, including electronic approvals by FHWA personnel. To assist with the implementation of e-construction, the FHWA Investment Review Board approved a pilot project in April 2015 to test tablet devices in several division offices. The purpose of the pilot project was to evaluate the use of two types of mobile devices (Apple® iPad® and Microsoft® Surface® Pro tablets) and provide recommendations on the potential for agencywide implementation. Division offices in Florida, Iowa, Michigan, Texas, Utah, and West Virginia participated in the initial phase of the pilot. Each office tracked and reported performance measures (for example, reduction in paper use and reduction in processing and approval times) using predefined data sources. The pilot agencies also reported information on the pros and cons of each device, the differences between shared and individually assigned devices, and the security and durability of the equipment in the field. In addition, pilot participants tested some mobile device applications for possible inclusion in USDOT's standard operating environment[14].
State DOTs are transforming their approach to highway projects to keep pace with today's changing, mobile work environment. Highway projects traditionally involve paper plan sets, paper documentation, and wet-ink signatures on contract documents and other approvals. Even with the introduction of computer-based management systems in recent decades, transportation agencies and contractors still print much of the documentation that was originally developed in electronic format simply because it is standard procedure. Recently, the highway industry started revolutionizing business to deliver projects more efficiently. The Federal Highway Administration and State Departments of Transportation are adopting e-construction, as a tool, to reduce paperwork and associated costs, facilitate more efficient project delivery, and improve communication and environmental sustainability. E-construction employs many tools, technologies, and practices that include mobile devices, software, and applications for field inspection and data collection; data hosting services such as data clouds, share sites, and virtual review rooms; and communications tools such as email, text, social media, and other intelligent technologies[15].

B. Mobile Devices for Inspection and Acceptance

According to the Texas division office, the most significant benefit it realized during the pilot was the ability to do various tasks anywhere because of the mobility of a tablet. The Texas participants reported increased efficiency in general but significantly in field inspections with photography for reports. Likewise, the Utah division reported benefits such as access to real-time information, a significant reduction in paper resources, and time savings because of access to current information. Utah also noted the user-friendly benefits of tablets compared to laptop computers, including lighter weight, small size, and touchscreen capabilities. The Pennsylvania Department of Transportation (PennDOT) adopted its first two mobile construction apps in 2015, that the agency estimates will save more than $22 million in 2 years through improved efficiency. The apps further PennDOT's commitment to e-construction by giving inspectors access to electronic forms at project sites. Now, inspectors use the software on their mobile devices to perform the same tasks directly from the field instead of preparing paper documents and traveling between their offices and construction sites to submit the reports.

The California Department of Transportation (Caltrans) distributed about 1,000 tablets to its field engineers in 2017-18, which covers half of the total field workforce. Inspectors in the field use tablets to access contract documents and work manuals, enter information, email interested parties, and conduct research. The devices cut costs and save time because they can reduce the need for traveling between the office and sites, lower environmental impact, and lower state vehicles' exposure to vehicular accidents. A recent survey shows that each tablet used by the Division of Construction resulted in an average reduction of 4.4 weekly trips between the field office and the job site- translates to an annual travel savings of $2.1 million[16]. Once the division provides all 2,000 field engineers with tablets, the annual savings could jump up to $3 million. As the users become more experienced in using tablets to collect and access information in the field, these savings might increase even more. When field tablet users can access documents remotely and enter data on the job site, they are making better use of their time than they would by physically retrieving documents, typing data, or completing forms in their office[17].

Furthermore, the New York City Department of Transportation (NYC DOT) has also taken part in its paperless operations. Their inspectors found tablets, perfect form factors as the devices are more portable and user-friendly and typically boot up faster than notebook computers. The devices have different price points and operating systems (Android, Apple iOS, and Windows). They choose the right one, depending on their agency's needs, existing infrastructure, and budget. NYC DOT's IT division has also launched a web-based street construction inspection app called 'DASH' that allows inspectors at sites to use the city's private cellular wireless network to transmit their data, reports and retrieve new assignments and furnished its workers with new tablets[17]. Florida DOT's (FDOT's) transition to digital as-builts also emerged from its previous investment in e-construction. Florida currently uses digitally signed PDFs for construction contract documents, which laid the foundation for capturing as-builts in a digital PDF format, and they are more efficient in collating the digitally signed PDFs for construction contract documents using productivity tools. The digital format enables storing more robust information, such as embedded photos, videos, and documents, as well as offers better navigation features, such as searchable text and hyperlinks to external content or bookmarks to locations within the file[18].

Consequently, the development of easy-to-use mobile applications can be advantageous for the construction industry by allowing them to perform and complete their day-to-day work activities[15]. In addition, mobile applications that focus on the usability aspect reduce operating costs borne by application developers. Apart from that, usability applied in the development of mobile applications not only increases the quality and performance of the interaction between interfaces but also increases the degree of user satisfaction on the dependency of the mobile application[17], [19]. The procession of development of affordable mobile technologies such as handheld computers, smartphones, and tablet PCs alongside the latest generation communications infrastructure (3G, WLAN, and GPRS) could provide the missing link to help address the ongoing drive for process improvement and re-valuing construction[10].

III. METHODS

The purpose of this paper is to document the state DOT practices for using mobile devices to support digitized project documentation and inspection. As part of this objective, existing literature was reviewed to identify previous practices in the digital transition of state DOTs using mobile devices. Then, an online survey questionnaire was built and emailed to the American Association of State Highway and Transportation Officials (AASHTO) Committee on Construction (AASHTO COC) voting members. AASHTO COC constitutes members from each of 50 U.S. states and District of Columbia Department of Transportation. A total of 43

complete responses were received for an 84% response rate, as presented in Figure 1. After collecting the raw data, data analysis was performed to visualize the results. Responses were collected from several divisions within the surveyed state DOT personnel, and examples of respondent divisions include “Construction” (86%), “Materials/Pavements” (12%), and “Project Delivery Management” division (9%). Moreover, (7%) respondents work in each of the “Inspection”, “Asset Data Management”, and “Innovation” divisions. Also, the response (2%) was collected from respondents who work in the “Geographic Information” division, “Planning Directory”, “CADD/Support”, and “Surveying/Support” divisions.

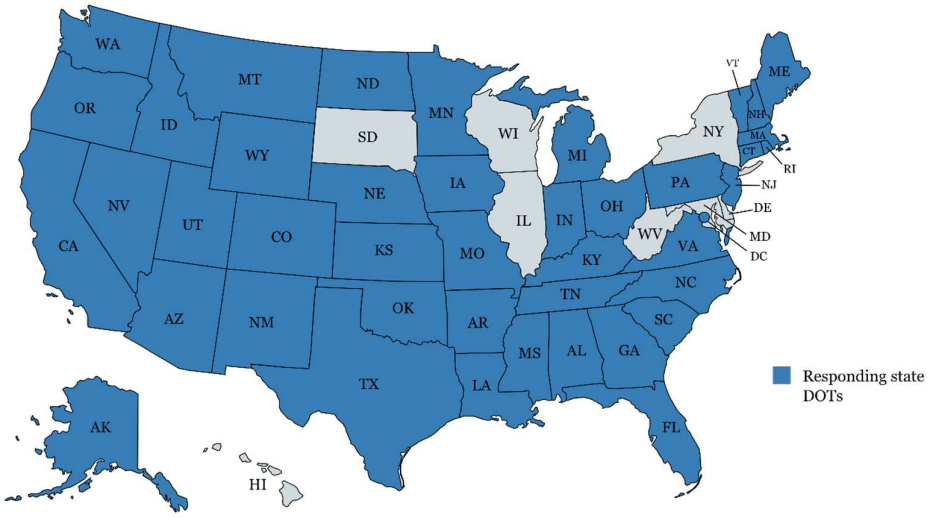

Figure 1. State DOTs participated in the survey (created with MapChart.net)

Respondents were asked to provide insights on the overall use of mobile devices, including use within an agency, the use among inspectors, an overview of inspectors’ use of business and personal devices, the means to provide mobile devices to inspectors, and the methods to administer and update mobile devices provided by contractors. Twenty-one inspection functions were provided in the survey questionnaire, and respondents were asked to select mobile devices and applications they frequently use to monitor project performance, quantity and location of materials delivered and stored on-site, quantity and quality of work performed, project progress status, and so on. The inspection functions are summarized in Table 1 and the results are presented in Figure 6.

TABLE I: INSPECTION FUNCTIONS AND THEIR MOBILE APPLICATIONS

Inspection Functions	
Access	Retrieving inspection documentation
	Retrieving project documents (plans and specs)
As-Builts	Collecting as-built information
	Developing 3D as-built models
Assisted Inspection	Conducting earthwork inspection and quantities
	Conducting erosion control inspection
	Conducting structural inspection and quantities
	Locating underground utilities and underground assets
Measuring	Measuring installed materials (pipe length, sidewalk, curb & gutter, etc.)
	Measuring material strength and temperature (concrete, base course, etc.)
	Measuring pavement thickness
Monitoring	Monitoring construction progress
Quality Management	Performing quality control/quality assurance of testing results
	Performing quality control/quality assurance of tolerance checks
	Sending reminders of material testing requirements based on recorded payment quantities
	Submitting documentation reports
	Submitting verification and documentation of work completed for payment
	Taking site photos and videos
Tracking	Tracking finished materials and inventory (pipe, rebar, etc.)
	Tracking material delivery
	Tracking the position of bulk material (concrete, asphalt, aggregate loads)

State DOTs have their own policies for the use of mobile devices developed for personal and/or DOT-issued mobile devices, which are shed into light in this study. Some state DOTs also provide resources that they follow while implementing their Standard Operating Procedures. Cost implications related to using mobile devices and the challenges they encounter while documenting data in the field were also captured in the study. Data collected from these questions were analyzed using k-means clustering, a generic yet efficient tool for finding groups or clusters in multivariate data. K-means clustering is the classification of similar data sets into different groups or clusters, where data in the same cluster share common features[20]. The purpose of the k-means clustering employed in this research is exploratory and aims to identify groups or common categories to help decision-makers while prioritizing resources, interventions, or strategies to address the most common or critical causes within each cluster effectively.

IV. Results and Discussion

A. Usage of mobile devices within agency

Initially, respondents were asked to indicate the levels within their agency to which mobile devices are issued Figure 2. From the responses in the figure, it is perceived that mostly In-House Inspectors", "Engineers", "Division Directors", and "Upper Executive Management" personnel are issued devices to perform Daily Work Reports in the field.

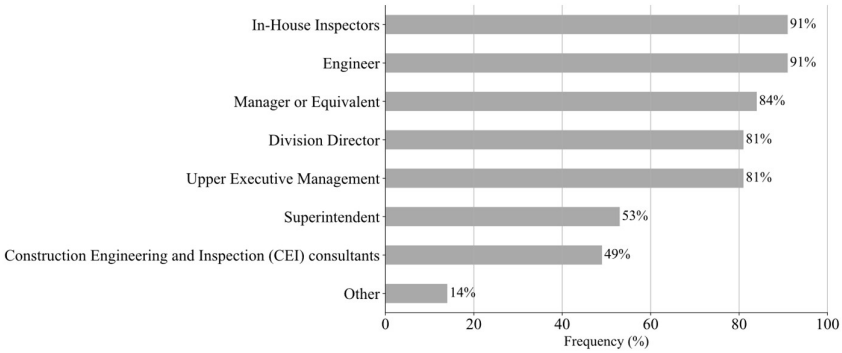

Figure 2. Mobile device usage within the agency at various levels

Secondly, respondents who indicated that mobile devices are issued to their in-house inspectors and/or Construction Engineering and Inspection (CEI) consultants were asked that what percentage of their agency's in-house inspectors and CEI consultants use mobile devices to perform their work. As noted in Figure 3, around 90% of their CEI consultants and 72% of their in-house inspectors use mobile device for data collection.

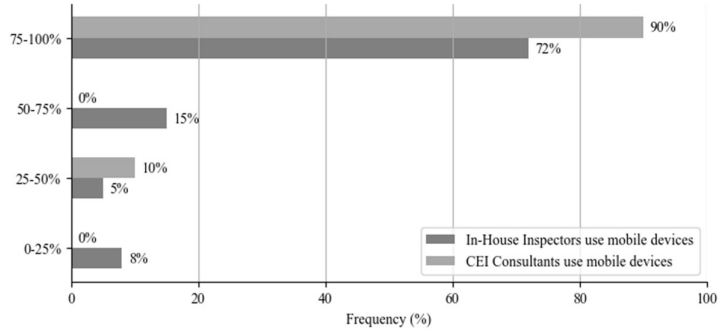

Figure 3. In-House Inspectors and CEI consultants use mobile devices to perform their work

From using mobile devices for daily work reports, respondents were then asked about how mobile devices are provided to inspectors and were allowed multiple selections among the options as presented in Figure 4. As 12% of respondents said that contractors provide them with mobile devices, they were further asked about how they are administered and updated if provided by the contractor. Response (80%) stated that mobile devices are updated and administered in-house by an agency or contractor and, at least, are administered in other ways.

Figure 4. How mobile devices are provided to inspectors and administered

Regarding the policies /standard operating procedures for mobile devices Figure 5, 64% of respondents reported that they have their developed policies, and some respondents also shared their state's mobile device-related policies and procedures: Alaska, California, Colorado, Iowa, Minnesota, Mississippi, Nebraska, North Carolina, Pennsylvania, Texas, Utah, and Virginia. Furthermore, some states (31%) have developed strategies for data documentation for the use of personal and/or DOT-issued mobile devices, and respondents also shared their state strategy guides: Colorado and Texas.

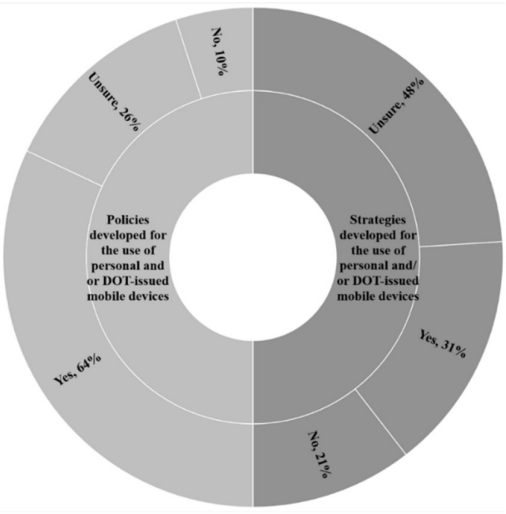

Figure 5. Policies and strategies developed for personal and/or DOT- issued mobile devices

B. Mobile devices usage

For all 21 inspection functions, state DOTs were more frequently reported using iOS devices instead of Android devices Figure 6. “iOS smartphones” and “iOS tablets” were reported to be used roughly equally by state DOTs for all 21 inspection functions. 85% reported that mobile devices, specifically “iOS smartphones,” were most frequently used for taking site photos and videos. DOTs stated less often devices used for inspections are “Android Smartphone” (24%) or “Android Tablet (32%)”; “Rovers” are rarely used for inspection functions other than “Conducting earthwork inspection and quantities” and “Measuring installed materials” selected by 26% respondents. iOS Smartphone was more frequently used (63%) than Android Smartphone (27%) across all 21 inspection functions. iOS Tablet was also more prevalent (76%) compared to Android Tablet (28%) for the same functions. Rovers were the least utilized, accounting for only 8% of inspection functions.

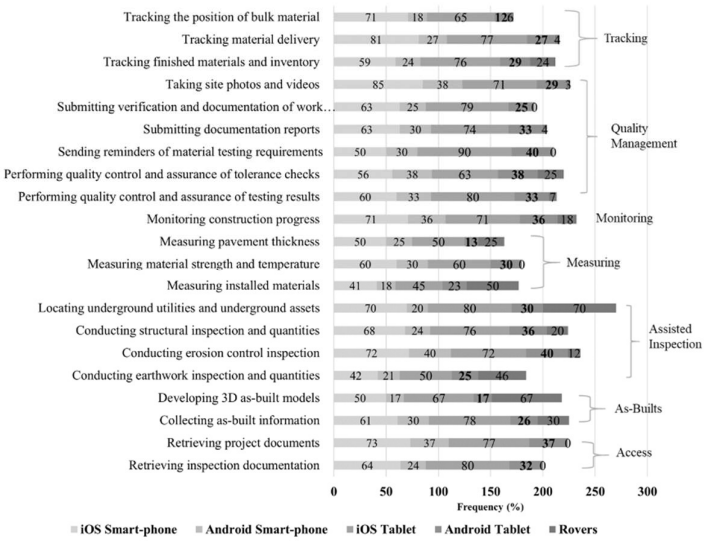

Figure 6. Types of mobile devices used for inspection functions

C. Mobile Devices Challenges and Implications

To determine different cost implications challenging state DOTs, k-means clustering was employed to classify the selected implications and break them into groups based on the respondents' answers from the given options. The k-means allows the identification of the number of clusters that provide the most parsimonious balance between minimizing the number of clusters and also minimizing the sum of square errors in each cluster[21]. The k-means clustering analysis grouped the data points into three clusters based on cost categories. Cluster 1 is characterized by high frequencies and percentages for operational costs, capital replacement, and software licenses, indicating these are predominant cost categories within this cluster. The number of clusters is then obtained by finding the "elbow" in the scree plot [22]. The scree plot identified an elbow point at Cluster 2, indicating optimal clustering at this point and potentially higher variability within Clusters 1 and 2 compared to Cluster 3. As for mobile devices challenges state DOTs experience, Cluster 1 is characterized by issues related to internet connectivity problems in rural areas and the cost of mobile devices across the agency. These issues show a high level of importance, with these topics dominating this cluster based on their high frequencies and percentage shares. Clusters 1 and 2 (Issues with data synchronization, Concern with data security, Limited time to train inspectors on the use of mobile devices, etc.) seem to have higher inertia values, indicating potentially higher variability within these clusters compared to cluster 3(Concerns with mobile devices becoming a safety hazard on the jobsite, Concerns with software bugs in mobile device applications, limited storage on mobile devices to access needed files and applications).

V. CONCLUSION

The use of mobile technology in construction sites has provided a workable and powerful platform for on-site construction management, and it is expected to pioneer the paradigm shift of conventional construction practices. However, there is still a need for an understanding of how mobile technologies can be productively utilized for construction inspection. Existing literature shows how, using a smartphone or tablet, workers on-site can quickly submit daily reports and change orders and reduce rework costs. This paper has objectified the current state-of-the-art practices of state DOTs in performing construction work using mobile devices in their digital transition. The findings from the survey, which were responded to by 43 different state DOTs, provide an overview of the current usage of mobile devices as a tool for digital construction. It is relevant for other state DOTs wishing to shift from paper-based documentation to digital. According to the survey results, there is an overview of the use of mobile devices within the agency, how mobile devices are issued to in-house inspectors and CEI consultants within the agency, how mobile devices are used for 21 inspection functions, and whether policies for the use of mobile devices are available. There are a number of states that have developed policies and strategies which can provide valuable insight and guidance to other states that are on the journey toward the use of mobile devices. In terms of mobile devices being used in most inspection functions on the sites, iPhones and iPads are the most

typical devices that are used. Moreover, the results also highlight the cost implications, which involve costs associated with capital and operational replacement of devices. As state DOTs continue to invest in using mobile devices for inspection, this study identified several challenges in knowledge that could be addressed through future research and guide state DOTs to choose devices that are most appropriate for the workforce and can ensure an increase in performance and efficiency to support through their digital transition. Future studies can build on this paper and provide case examples to gather further details on individual state DOTs' uses and their perceptions of using mobile devices for inspection functions.

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REFERENCES

[1] P. Stefanakis, "Digitalizing the construction site management: assessing and boosting the use of digital mobile tools for capturing data on construction on-site activities," 2019.
[2] B. V. Barbarosoglu and D. Arditi, "Mobile applications for the construction industry," Proceedings of International Structural Engineering and Construction, vol. 3, no. 1, 2016.
[3] D. Tran, C. Harper, and R. Sturgill, Highway Infrastructure Inspection Practices for the Digital Age, no. NCHRP Project 20-05, Topic 52-01. 2022.
[4] A. Aboah, M. Boeding, and Y. Adu-Gyamfi, "Mobile Sensing for Multipurpose Applications in Transportation," J. Big Data Anal. Transp., vol. 4, no. 2–3, pp. 171–183, Dec. 2022, doi: 10.1007/s42421-022-00061-8.
[5] G. B. Dadi et al., Technological Capabilities of Departments of Transportation for Digital Project Management and Delivery. Washington, D.C.: Transportation Research Board, 2022, p. 26738. doi: 10.17226/26738.
[6] H. S. Ahmad, I. M. Bazlamit, and M. D. Ayoush, "Investigation of document management systems in small size construction companies in Jordan," Procedia Engineering, vol. 182, pp. 3–9, 2017.
[7] A. Sattineni and T. Schmidt, "Implementation of Mobile Devices on Jobsites in the Construction Industry," Procedia Engineering, vol. 123, pp. 488–495, 2015, doi: 10.1016/j.proeng.2015.10.100.
[8] Isaac Sacolick, "Construction Industry Dead Last in IT Spend," ENR: Engineering News Record, 2012. [Online]. Available: https://www.enr.com/articles/8573-construction-industry-dead-last-in-it-spend
[9] S. Bowden and A. Thorpe, "Mobile communications for on-site collaboration," presented at the Proceedings of the Institution of Civil Engineers-Civil Engineering, Thomas Telford Ltd, 2002, pp. 38–44.
[10] S. Bowden, A. Dorr, T. Thorpe, and C. Anumba, "Mobile ICT support for construction process improvement," Automation in construction, vol. 15, no. 5, pp. 664–676, 2006.
[11] J. Wong, X. Wang, W. Chair, H. Li, G. Chan, and H. Li, "A REVIEW OF CLOUD-BASED BIM TECHNOLOGY IN THE CONSTRUCTION SECTOR," 2014.
[12] N. B. Chong, L. Uden, and M. Naaranoja, "Knowledge management system for construction projects in Finland," IJKMS, vol. 1, no. 3/4, p. 240, 2007, doi: 10.1504/IJKMS.2007.012524.
[13] G. O. Bigirumuremyi, A. Y. Mohamed, and F. Nouban, "Analysis of Innovation in Construction from the Perspective of Modern Project Management," vol. 7, no. 12, 2022.
[14] T. Vilkko, T. Kallonen, and J. Ikonen, "Mobile fieldwork solution for the construction industry," in 2008 16th International Conference on Software, Telecommunications and Computer Networks, Split, Dubrovnik, Croatia: IEEE, 2008, pp. 269–273. doi: 10.1109/SOFTCOM.2008.4669493.
[15] Kathryn Weisner, Bryan Cawley, and Alicia Sindlinger, "The Age of e-Construction," in Public Roads - July/August 2017, FHWA-HRT-17-005., Federal Highway Administration, 2017. [Online]. Available: https://highways.dot.gov/public-roads/julyaugust-2017/age-e-construction
[16] J. Hancock, "Construction Materials Management Systems: Survey of State Practice", doi: 2018.
[17] Wylie Wong, "How the NYC Department of Transportation Used Tablets to Go Paperless," MOBILITY. [Online]. Available: https://statetechmagazine.com/article/2012/07/how-nyc-department-transportation-used-tablets-go-paperless
[18] United States. Department of Transportation. Federal Highway Administration.., "Innovator Newsletter September/October 2022 Issue 92", doi: 10.21949/1521850.
[19] Mile Marker, "Construction Turns to Tablets for Efficiency," Winter -2020 2019. [Online]. Available: https://dot.ca.gov/programs/public-affairs/mile-marker/winter-2019-2020/construction-turns-to-tablets-for-efficiency
[20] A. A. Adebisi, O. E. Olusayo, and O. S. Olatunde, "An exploratory study of k-means and expectation maximization algorithms," British Journal of Mathematics & Computer Science, vol. 2, no. 2, pp. 62–71, 2012.
[21] T. Hothorn and B. S. Everitt, A handbook of statistical analyses using R. Chapman and Hall/CRC, 2009.
[22] T. M. Kodinariya and P. R. Makwana, "Review on determining number of Cluster in K-Means Clustering," International Journal, vol. 1, no. 6, pp. 90–95, 2013.