Assessing the Impacts of Mobile Technology on Project Inspection

Julian Yamaura (corresponding)
Research Assistant
University of Washington
Civil & Environmental Engineering
Box 352700
Seattle, WA 98195
Phone: (206) 616-1259
E-mail: yamauraj@uw.edu

Stephen T. Muench, Ph.D., P.E.
Associate Professor
University of Washington
Civil & Environmental Engineering
Box 352700
Seattle, WA 98195
Phone: (206) 616-1259
E-mail: stmuench@uw.edu

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As mobile technology becomes widely available and affordable, transportation agencies can use this technology to streamline operations involved within project inspection. A pilot project conducted with three State Departments of Transportation examined the business process of project inspection and looked for process improvement opportunities using mobile technologies. Previous work informed the development of a specific mobile technology solution, named *HeadLight*, which was compared to legacy construction inspection processes. Outcomes were quantified in relation to productivity, data quality, and data availability. Results indicate that project inspectors using mobile technology experienced productivity gains on the order of 25%, collected and shared 2.0 times as many observations, and improved the timeliness of daily reports and overall data availability. Additionally, the mobile technology solution is found to enable more complete and consistent data, improved accessibility throughout a project office and DOT. All these outcomes indicate mobile technology for project inspection is a substantial workforce multiplier. Further study into improved data quality and availability may identify more impacts within the construction inspection process and to an owner agency’s decision making processes.
INTRODUCTION

As the accessibility of affordable mobile technology continues to increase, transportation agencies can use this technology to streamline operations where opportunities exist for process improvement. Substantial literature on mobile technology in the construction industry has focused on the benefits of sharing up-to-date project reference documents from the project office to the field and vice versa (e.g., 1, 2, 3). These studies have generally determined that the time savings associated with sharing of project documents did not affect the progress of the overall project, but allowed inspectors to spend more time performing their primary duty of inspecting construction activities. Recent investigations have been focused on using mobile technology to reduce the efforts involved in generating inspection documentation and to simplify the customer’s business model (e.g., 2, 4, 5, 6, 7). Most applications tend to be tailored for contractors in the building industry and support a specific component of the inspection process. Finding a mobile application that can be customized to meet a specific customer’s current business, administrative, and inspection process can be challenging.

Scope

This paper describes a pilot project that examines how mobile technology can be used as a tool to improve the business process associated with State Department of Transportation (DOT) project inspection. Specifically, the pilot project addresses the construction inspection process for three state DOTs: the Washington, Minnesota, and Texas Department of Transportation agencies (WSDOT, MnDOT, and TxDOT respectively). A mobile technology solution, specifically developed for the construction inspection process through previous work (8) is deployed on a limited basis to WSDOT, MnDOT, and TxDOT. The mobile technology solution, named HeadLight, focuses on features and capabilities that allow project inspectors to record a variety of observations and automatically generate required daily inspection reports based on those observations. This study quantifies mobile technology impacts by comparing the existing inspection process for each DOT with that using HeadLight over three dimensions typical of software evaluation: productivity, data quality, and data availability (9).

BACKGROUND: PREVIOUS RESEARCH

This study is part of a larger effort to develop and deploy mobile technology for DOT project inspection. An initial part of this effort (8) was to develop user requirements based on interviews with WSDOT and TxDOT personnel. Key findings from these interviews were:

- The information collected about projects through inspection activities is valuable.
- Not all inspection information is saved to the project file due to information being documented and shared using various strategies/channels (email correspondence, information written on notebooks, etc.).
- Collecting visual documentation and inspection information metadata (location information, time stamp, etc.) plays an important role in the impact of project inspection as it often helps to provide clear, objective evidence of items being observed.
- Project inspectors must be able to look up information contained in project reference documents (e.g., plans, specifications, special provisions) while in the field.
- On average, project inspectors spend over five hours a day performing tasks that mobile technology can address. Those tasks include transposing information into the computer from handwritten notes, looking up information in project reference documents, and performing calculations as part of their inspection duties.
Project inspectors identified challenges in documenting information while out in the field, which impacts their ability to submit daily documentation in a timely manner. Interview participants reported a high level of comfort with the use of technology, both personally and as part of their work.

Based on these identified challenges, interviewees were presented with a variety of mobile technologies for enhancing the project inspection process. Interviewees ranked these capabilities in the following order:

1. Consistent, seamless image capture, allowing inspectors to write notes on the image, and compress and upload easily.
2. Relevant email correspondence can be tagged and saved along with project information.
3. QR codes for materials acceptance or prefabricated components.
4. Updates in real time, where items can be flagged immediately and notifications sent directly to those in need of them.
5. Automatically import weather data based on location.
6. Perform calculations automatically in the field for daily inspection reports.
7. eSignatures for inspection or quantity reports.

Snow et al. (8) concluded that these features deployed in an integrated mobile environment would provide value both to project inspection personnel in the field and engineering personnel in project and central offices.

DEFINITIONS

Personnel Roles

This research focused on three main personnel roles identified within the participating DOTs:

- **Project inspectors.** Responsible for performing inspection on projects in the field. This individual does not manage others and it typically the personnel resource dedicated to one or more active projects in the field at a time (10, 11, 12, 13, 14).
- **Project engineers.** In charge of their field office and are accountable for all project related activity occurring through that field office (10, 11, 12, 13, 14).
- **Management.** Personnel not within a particular field office, but involved when items are escalated or conflict resolution is necessary. Titles within the management role can range from State Construction Engineer to Construction Section Director to Assistant Regional Administrators (10, 11, 12, 13, 14).

**Business Process: Project Inspection**

Refers to “the examination and testing of goods or services to determine conformance to the purchase order requirements, specifications, quality and quantity.” This includes inspection of all bid items and project activities DOT inspection personnel are responsible for in the field during active construction and maintenance projects (15).

**Business Process: Project Documentation**

DOT project inspectors in Washington, Minnesota, and Texas are required to produce documentation in the field to record inspection information. The purpose of that information is to communicate the facts of what transpired on the job site including activities, materials, and test results and whether they conform to agency plans, specifications, and general quality standards.
This includes documentation of safety, accidents, traffic control, materials, construction practices, equipment, personnel, environment, weather, field issues etc. Additionally, project inspectors document contract items such as change orders and pay or bid items that were worked on and to what extent in order to determine subsequent payment and serve as a legal reference.

A key requirement for all three DOTs is to observe and document general project progress and activities occurring in the field. For the States of Washington and Texas project inspectors are required to submit daily reports of activities in the field (10, 11, 12, 13). In Washington State these forms are called Inspector Daily Reports (IDRs), while in Texas they are referred to as Daily Work Records (DWRs). Project inspectors in Minnesota are required to record daily activities as well, but they submit documentation on a weekly basis known as Weekly Construction Reports (WCRs) (14). For all three DOTs, the daily and weekly reports perform essentially the same function. They are to be a dispassionate record of what transpired in a day, objectively documenting project related activities.

Each DOT involved in this study has additional inspector documentation requirements that are not evaluated as a part of this study. For example, forms and documents to record pay items other than what is gathered on a typical daily or weekly construction report were not included within the scope of this research. This research assumes that the findings for the daily and weekly construction reports can similarly be applied to the additional agency specific documents to further extend the impacts of using mobile technology.

Mobile Technology

For this paper “mobile technology” refers to both hardware and software that can be used in concert to allow integrated real-time field entry of project-related information, and office and field access to that information.

Mobile Hardware. The Apple iPad Air is used because it integrates the following key hardware features needed to collect, process, document, and share project inspection information:

- **Camera**: built-in high resolution cameras for capturing images and videos, which eliminates the need to carry a separate digital camera.

- **Connectivity**: connect to a cellular or Wi-Fi network provides access to online content. This capability allows inspectors to share inspection information with other personnel and allows access to project reference documents from the field.

- **Computing Power**: enables tasks such as word processing and number computation. Computing power allows inspectors to document inspection observations and generate daily reports directly from the field.

- **Global Positioning System (GPS)**: enable tracking of location data. This feature automatically tags inspection observations with precise location information.

- **Integrated Sensors**: common tablet built-in sensors such as microphones, accelerometers, barometers, and magnetometers can be used as measuring devices in the field.

Additionally, each iPad Air was outfitted with a waterproof protective casing. A handstrap was outfitted on the back of the device to allow inspectors to safely and conveniently carry the device in the field. Android tablets and Microsoft’s Surface tablet also met the hardware requirements for the pilot study although the scope of the research mandated that only one mobile hardware platform be selected. As such, the existing level of support for the iPad and iOS
operating system at participating agencies during this study factored in to the decision to select the iPad. The mobile hardware and screenshots of the HeadLight software are shown in Figures 1a, 1b, and 1c.

**FIGURE 1a** Examples of various observation recordings available on the mobile hardware outfitted with the waterproof protective casing.
FIGURE 1b Screenshot of the *dashboard* menu on the HeadLight Mobile Client.

FIGURE 1c Screenshot of the documents menu in the Web Client.
Software Application The mobile technology software, named *HeadLight*, was developed by Pavia Systems, Inc. based on findings from Snow et al. (8). *HeadLight*’s three main components are:

- **Mobile Client.** The application installed on the mobile hardware. It provides a set of observational features and tools to allow project inspectors to submit documentation directly from the field. It also enables project inspectors to access all project reference documents from the field such as project plans, specifications, special provisions and other project manuals.

- **Web Client.** Application viewable by office personnel. It allows project engineers, management, and others with permission to access information collected by the Mobile Client through a secure web interface.

- **Web Service.** Manages the data and information amongst the mobile clients and provides a centralized, secure, storage architecture by which the data is made available to both the Web Client, and other data systems that may reside within an agency.

**METHOD**

The pilot program described by this paper consists of the following key activities:

- **Training.** Two-hour introductory training sessions were given to all participates in order to familiarize them with the Mobile and Web Clients.

- **Field testing.** There was a one-month testing period for each DOT in which the mobile technology was used on a pilot basis for construction inspection on multiple projects. Personnel using *HeadLight* were monitored in the field and key data recorded.

- **Technical support.** Researcher located in the field roamed between projects and participants to address issues that arose during their use of the mobile technology.

- **Participant interviews.** Participants were interviewed after the testing period to gather feedback, provide further explanation to field testing observations, and corroborate field observations.

This paper addresses results from the field testing and participant interviews only.

Mobile technology impact was quantified for three different outcomes:

- **Productivity.** Defined as the time spent on data entry, searching through project reference documents, and performing calculations.

- **Data quality.** Defined as the quantity, completeness and consistency of the information collected by the project inspector.

- **Data availability.** Defined as the accessibility (including timeliness) of project inspection information to project engineers and management.

The following data sources were used to quantify the three outcomes:

- **Direct measurements.** Researchers used quantifiable measuring techniques to evaluate the metrics for the projected outcomes. The presence of researchers likely had an effect on project inspector actions, however this effect was considered minor enough to ignore.

- **Inspection report analysis.** Researchers reviewed inspection reports to categorize and quantify recorded observations. Inspection reports were reviewed in daily increments.
Since MnDOT inspectors generate weekly reports, the information from the MnDOT WCRs was broken out into individual days.

- **Interviews.** Researcher administered structured participant interviews after field testing.

Researchers compared measurements between the existing legacy construction inspection process and the experimental *HeadLight* process. In some cases the interview was used to ask participants to estimate times not measured during field testing.

The following section describes the approach taken to evaluate the three outcomes.

**Productivity**

We used the following metrics to quantify productivity:

- Time spent creating construction report documents
  - **Direct measurements.** Researchers used a stopwatch to measure the time spent creating inspection reports using the legacy process and *HeadLight*.
  - **Interviews.** Researchers asked inspectors how much time was saved/incurred from using *HeadLight* compared to their legacy inspection process.

- Time spent searching for content in the project reference documents
  - **Direct measurements.** Researchers used a stopwatch to measure the time spent looking for specific items the project reference documents as required in the field. Physical paper versions were used for the legacy process and electronic versions were used for the *HeadLight* process.

- Time saved from reduced travel off site to complete or submit documentation
  - **Interviews.** Researchers asked participants to determine any travel time savings stemming from the use of the *HeadLight* process.

**Data Quality**

Data quality, a typical metric used to measure quality performance in the Information Technology industry, can be identified by the completeness and consistency of the inspection information (9). For this pilot project, *data completeness* is defined as the capturing of all data components associated with an inspection observation needed to objectively portray the actual conditions of the work performed and *data consistency* is defined as the ability to collect and report inspection observations using a consistent single entry process to eliminate the potential for errors and omissions (10).

We used the following metrics to quantify data quality:

- Composition of observation entries
  - **Direct measurements** – research assistants counted the amount of observations by type for both the legacy and *HeadLight* processes.

- Amount of observations made per inspector per day
  - **Direct measurements.** Researchers quantified the number of observation type in the inspection reports. Observation types were: photo, video, audio, density, text, equipment on site, personnel on site, temperatures of materials placed on site, weather, start/stop times related to contract work hours or construction activities, and calculations to determine material quantities. Since the formatting of the daily report differs from one DOT agency to another, guidelines were created to
account for the number of observations in the reports in a consistent manner. A total of 76 WSDOT IDRs, 28 MnDOT WCRs, and 60 TxDOT DWRs for each DOT’s legacy process were reviewed and compared with those reports generated during the field testing.

- The fraction of observations that reference a specific time and/or location.
  - **Direct measurements.** Researchers counted the number of observations associated with a specific time and location. This was done by document review for the legacy process. This was designated as 100% for the HeadLight process since HeadLight automatically tags all observations with time and location.

The amount of observations collected per inspector per day were measured to determine the change in the amount of information resulting from the use of mobile technology. Another important aspect that contributes to data quality is using a variety of observation types to represent the construction activities performed onsite. For example, including visual references such as photographs can significantly improve the way inspectors describe the progress of work or issues that may arise.

**Data Availability**

We used the following metrics to quantify data availability:

- Accessibility of inspection observations and daily inspection reports
  - **Interviews.** Researchers asked project engineers and management staff to qualitatively assess how easy/difficult it was to access observations and inspection reports.
- Percentage of daily inspection reports submitted within 24 hours and 72 hours
  - **Direct measurement.** Researchers counted the amount of inspection reports that were available to project engineers and management staff within 24 hours and 72 hours of the observed working day.

**Research Participants**

A total of 24 inspectors and 11 project engineers and management personnel participated in this pilot project. Project inspectors participated in the mobile client training session, performed inspection on projects using HeadLight, and participated in interviews. Project engineers and management personnel participated in the web client training session, reviewed inspection observations and daily inspection reports using the web client, and participated in interviews. The following shows the breakdown of participants by agency:

- **WSDOT:** 6 project inspectors and 2 project engineers/management.
- **MnDOT:** 9 project inspectors 5 project engineers/management.
- **TxDOT:** 9 project inspectors and 4 project engineers/management.

Table 1 summarizes the projects included in the field test. These projects were selected (i.e., not chosen at random) based on opportunity (i.e., project was being constructed during the field test window), type (e.g., earthwork, roadway, structure, etc.) and size (construction cost and duration).
TABLE 1 DOT Projects Involved in the field test

<table>
<thead>
<tr>
<th>Agency</th>
<th>Project Number</th>
<th>Project Name</th>
<th>Cost (dollars)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSDOT</td>
<td>8569</td>
<td>Two-way transit &amp; HOV operations, stage 3a - EV Bellevue Way ramps</td>
<td>$7,399,235</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>8542</td>
<td>WB east channel bridge expansion joint replacement</td>
<td>$1,153,045</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>8583</td>
<td>High Point St to SR 410 Watson St paving &amp; signal</td>
<td>$2,139,175</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>8576</td>
<td>SR 410 Scatter Creek Bridge Seismic</td>
<td>$697,344</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>8584</td>
<td>SR 18 Taylor Creek Scour Protection</td>
<td>$138,990</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>8565</td>
<td>SR 18 I/C to S 288th ST Seismic Retrofit</td>
<td>$4,644,837</td>
<td>215</td>
</tr>
<tr>
<td></td>
<td>8559</td>
<td>S 272nd ST Vic to Rose ST Seismic Retrofit</td>
<td>$8,504,188</td>
<td>445</td>
</tr>
<tr>
<td>MnDOT</td>
<td>2710-42</td>
<td>Railroad Bridge</td>
<td>$5,439,300</td>
<td>279</td>
</tr>
<tr>
<td></td>
<td>2710-2440B</td>
<td>Concrete and Scour Repair</td>
<td>$1,394,800</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>8282-123</td>
<td>Weigh Scales and Concrete Rehab</td>
<td>$1,946,308</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>6280-308</td>
<td>I-35E Corridor Project</td>
<td>$119,834,500</td>
<td>694</td>
</tr>
<tr>
<td></td>
<td>2772-99</td>
<td>Noise Walls</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2781-456</td>
<td>Wood Noise Wall</td>
<td>$1,077,000</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2781-458</td>
<td>Micro Surfacing and TMS Improvements</td>
<td>$208,000</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1909-95</td>
<td>Turn Lanes</td>
<td>$6,798,653</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>1009-24</td>
<td>Bridge Construction</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>6280-367</td>
<td>Construct MnPass Lanes</td>
<td>$95,110,192</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2706-226</td>
<td>Louisiana Ave Bridge</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2785-403</td>
<td>Grading, Bit Surfacing, Bit Mill and Overlay, Lighting and Bridges</td>
<td>$5,406,090</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2783-136</td>
<td>4th Street Ramp Design</td>
<td>$12,588,932</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2738-28</td>
<td>Grading, Bit Surfacing, Retaining Walls, Signals, Signing, Lighting, TMS, ADA and Bridge</td>
<td>$17,112,000</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>1982-182</td>
<td>Bituminous Shoulder Replacement</td>
<td>$1,401,500</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>8825-471</td>
<td>IDIQ</td>
<td>$5,490,821</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>2732-108</td>
<td>Drainage Repair</td>
<td>$91,000</td>
<td>7</td>
</tr>
<tr>
<td>TxDOT</td>
<td>0027-12-105</td>
<td>Widen to 6 – lane rural freeway, frontage roads, ITS and TSM</td>
<td>$135,868,539</td>
<td>1079</td>
</tr>
<tr>
<td></td>
<td>0500-03-462</td>
<td>Widen &amp; reconstruct to 10 main lanes, two 3 lane Frontage</td>
<td>$77,483,151</td>
<td>1135</td>
</tr>
<tr>
<td></td>
<td>0050-06-080</td>
<td>US-290 Widening</td>
<td>$48,599,234</td>
<td>700</td>
</tr>
<tr>
<td></td>
<td>0271-05-037</td>
<td>Construct entrance and exit ramps, convert EB Frontage</td>
<td>$10,742,565</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>0050-06-081</td>
<td>Reconstruct and widen to 8 main lanes with 2 reversible</td>
<td>$85,215,954</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>0050-08-087</td>
<td>Reconstruct and widen to 8 main lanes with 3 reversible</td>
<td>$135,455,756</td>
<td>1052</td>
</tr>
<tr>
<td></td>
<td>1006-01-059</td>
<td>Widen to 4 lane roadway with center left turn lane</td>
<td>$7,690,214</td>
<td>322</td>
</tr>
</tbody>
</table>
RESULTS
This section presents aggregated results that highlight differences in inspector productivity, data quality, and data accessibility between the legacy and HeadLight processes.

Productivity

TABLE 2 Time Spent Creating Construction Report Documents and Searching For Content in Project Reference Documents

<table>
<thead>
<tr>
<th>Productivity Metric</th>
<th>Inspection Method</th>
<th>WSDOT</th>
<th>MnDOT</th>
<th>TxDOT</th>
<th>All DOTs^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average time per day taken to create daily inspection reports (minutes)</td>
<td>Legacy</td>
<td>37.75</td>
<td>15.00</td>
<td>27.50</td>
<td>26.75</td>
</tr>
<tr>
<td></td>
<td>HeadLight</td>
<td>0.48</td>
<td>0.25</td>
<td>0.12</td>
<td>0.28</td>
</tr>
<tr>
<td>Difference</td>
<td>37.27</td>
<td>14.75</td>
<td>27.38</td>
<td>26.47</td>
<td></td>
</tr>
<tr>
<td>Factor^b</td>
<td>78.6</td>
<td>60.0</td>
<td>229.2</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>Average time taken to search for content in project reference documents (minutes)</td>
<td>Legacy</td>
<td>N/A(^c)</td>
<td>10.50</td>
<td>6.20</td>
<td>8.35</td>
</tr>
<tr>
<td></td>
<td>HeadLight</td>
<td>2.24</td>
<td>1.21</td>
<td>3.68</td>
<td>2.45</td>
</tr>
<tr>
<td>Difference</td>
<td>N/A(^c)</td>
<td>9.29</td>
<td>2.52</td>
<td>5.91</td>
<td></td>
</tr>
<tr>
<td>Factor^b</td>
<td>N/A(^c)</td>
<td>8.7</td>
<td>1.7</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Average time per day taken to search for content in the project reference documents(^d) (minutes)</td>
<td>Legacy</td>
<td>65.14</td>
<td>39.90</td>
<td>107.70</td>
<td>70.91</td>
</tr>
<tr>
<td></td>
<td>HeadLight</td>
<td>23.09</td>
<td>4.60</td>
<td>63.92</td>
<td>30.53</td>
</tr>
<tr>
<td>Difference</td>
<td>42.05</td>
<td>35.29</td>
<td>43.79</td>
<td>40.38</td>
<td></td>
</tr>
<tr>
<td>Factor^b</td>
<td>2.8</td>
<td>8.7</td>
<td>1.5</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Average travel-time per day per inspector savings (minutes)</td>
<td>None. Only the difference is reported.</td>
<td>45</td>
<td>50</td>
<td>25</td>
<td>40</td>
</tr>
</tbody>
</table>

Notes:

a. Average of the three DOT values
b. Legacy value divided by HeadLight value. In the spirit of force multipliers this is a sketch indication of the force multiplier for the reported metric.
c. Not measured.
d. The Factor of time saved using HeadLight values were used to calculate the average time taken to search for contents per day. While no comparison to the current process can be made, on average, WSDOT inspectors spent an average of over 2 minutes to search for any one key search topic using HeadLight. This correlates to the time spent for both MnDOT and TxDOT using HeadLight so similar outcomes were anticipated in terms of time savings.

TABLE 3 Time Saved from Reduced Travel Off-Site to Complete or Submit Documentation

<table>
<thead>
<tr>
<th>Agency</th>
<th>Average Time Saved per Inspector per Day (Interview Response)</th>
<th>Average Time Saved per Inspector per Day (Measured Activities)</th>
<th>Productivity Gain Assuming an 8 hr day^a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WSDOT</td>
<td>MnDOT</td>
<td>TxDOT</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Number of inspectors</td>
<td>6</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Photo</td>
<td>778</td>
<td>1,025</td>
<td>460</td>
</tr>
<tr>
<td>Video</td>
<td>13</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>Text</td>
<td>441</td>
<td>101</td>
<td>364</td>
</tr>
<tr>
<td>Equipment</td>
<td>366</td>
<td>22</td>
<td>841</td>
</tr>
<tr>
<td>Personnel</td>
<td>206</td>
<td>45</td>
<td>419</td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Weather</td>
<td>412</td>
<td>812</td>
<td>572</td>
</tr>
<tr>
<td>Start/Stop</td>
<td>4</td>
<td>68</td>
<td>73</td>
</tr>
<tr>
<td>Material</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,224</strong></td>
<td><strong>2,127</strong></td>
<td><strong>2,754</strong></td>
</tr>
</tbody>
</table>

Notes:

a. Calculated as 8 hours / (8 hours – average time saved per day). This amounts to a productivity gain.

b. WSDOT’s time saved was not calculated because no data was collected on legacy process times. Therefore, the time estimated by interviewees (column 1) was used as a reasonable substitute.

---

Data Quality

**TABLE 4 Composition of Observation Entries**

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>WSDOT</th>
<th>MnDOT</th>
<th>TxDOT</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of inspectors</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>Photo</td>
<td>778</td>
<td>1,025</td>
<td>460</td>
<td>2263</td>
</tr>
<tr>
<td>Video</td>
<td>13</td>
<td>45</td>
<td>25</td>
<td>83</td>
</tr>
<tr>
<td>Text</td>
<td>441</td>
<td>101</td>
<td>364</td>
<td>906</td>
</tr>
<tr>
<td>Equipment</td>
<td>366</td>
<td>22</td>
<td>841</td>
<td>1,229</td>
</tr>
<tr>
<td>Personnel</td>
<td>206</td>
<td>45</td>
<td>419</td>
<td>670</td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Weather</td>
<td>412</td>
<td>812</td>
<td>572</td>
<td>1,796</td>
</tr>
<tr>
<td>Start/Stop</td>
<td>4</td>
<td>68</td>
<td>73</td>
<td>145</td>
</tr>
<tr>
<td>Material</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,224</strong></td>
<td><strong>2,127</strong></td>
<td><strong>2,754</strong></td>
<td><strong>7,105</strong></td>
</tr>
</tbody>
</table>
FIGURE 2 Composition of the observation entries by type for each DOT.
TABLE 5 Average Number of Observations Made per Inspector per Daya

<table>
<thead>
<tr>
<th>DOT</th>
<th>Legacy Processb</th>
<th>HeadLight</th>
<th>Factorc</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSDOT</td>
<td>20.1</td>
<td>30.2</td>
<td>1.5</td>
</tr>
<tr>
<td>MnDOT</td>
<td>5.5</td>
<td>19.9</td>
<td>3.6</td>
</tr>
<tr>
<td>TxDOT</td>
<td>25.1</td>
<td>25.0</td>
<td>1.0</td>
</tr>
<tr>
<td>All Agencies</td>
<td>16.9</td>
<td>25.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Notes:

a. Not all participants were active each day on the project site so any non-active days were excluded for this analysis.
b. Calculated by counting all observations in the inspection reports and dividing it by the total number of working days accounted for by each report.
c. Headlight / Legacy Process = Factor

TABLE 6 Fraction of Observations that Reference a Specific Time and/or Location

<table>
<thead>
<tr>
<th>DOT</th>
<th>Time Associated with Observations</th>
<th>Location Associated with Observationsa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Legacy Process</td>
<td>HeadLight</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>-----------</td>
</tr>
<tr>
<td>WSDOT</td>
<td>50.4%</td>
<td>100%</td>
</tr>
<tr>
<td>MnDOT</td>
<td>2.7%</td>
<td>100%</td>
</tr>
<tr>
<td>TxDOT</td>
<td>0.8%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Notes:

a. Location information was counted if the observation included any of the following: station location, mile post numbers, or GPS coordinates.

Data Availability

Accessibility of inspection observations and daily inspection reports
During the interview sessions, project engineers and management personnel were asked to describe how the mobile technology solution changed the way they accessed observations and daily inspection reports. Six out of six respondents (five interviewees skipped this question) answered that the availability of the inspection information improved. Five out of seven respondents (four interviewees skipped this question) answered that the availability of the daily inspection reports improved while two out of seven respondents (four interviewees skipped this question) answered that there was no change to the availability of the daily inspection reports.

Percentage of daily inspection reports submitted within 24 hours and 72 hours
Direct measurements of WSDOT daily inspection reports submission times revealed that using the legacy process, 55% of reports were submitted within 24 hours and 73% were submitted within 72 hours. Using HeadLight, WSDOT inspectors submitted 81% of reports within 24 hours and 92% within 72 hours. This pilot project did not have access to submission times for MnDOT and TxDOT reports so only WSDOT data are reported.
DISCUSSION

Productivity
DOTs in this pilot project achieved an average time savings of 1.59 hours per inspector per day by using mobile technology. The time savings came from performing tasks such as documentation and administrative duties as well as reduced travel. Analysis of this result indicated that an overall productivity gain of 20% (1.59 hrs. divided by a typical 8 hour day) was observed from using the mobile technology solution to create daily inspection reports. Since the scope of this pilot project did not cover all project inspector responsibilities, a more broad application of mobile technology beyond this scope will likely result in additional productivity gains.

Workforce Multiplier
The outcome of increased inspector productivity can be seen as an increase in the capacity of DOT workforce without requiring additional staff; in other words, a workforce multiplier (Table 7). Of course, multiplying the virtual gain in workforce by annual salary can show additional value gained from use of mobile technology for project inspection. The ultimate benefit/cost ratio for mobile technology is more complex because it depends on (1) lifecycle cost of the technology, (2) impacts beyond project inspector time (e.g., other affected personnel’s time, changes in data amount, quality and use – see next section, etc.), and (3) the potential for mobile technology to enable future value added features.

<table>
<thead>
<tr>
<th>DOT</th>
<th>Current Project Inspector Workforce</th>
<th>Workforce Multiplier based on Mobile Technology Use(^a)</th>
<th>Virtual Gain in Workforce(^b)</th>
<th>New Virtual Workforce(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSDOT</td>
<td>397</td>
<td>1.23</td>
<td>91</td>
<td>488</td>
</tr>
<tr>
<td>MnDOT</td>
<td>250</td>
<td>1.26</td>
<td>65</td>
<td>315</td>
</tr>
<tr>
<td>TxDOT</td>
<td>1,092</td>
<td>1.25</td>
<td>273</td>
<td>1,365</td>
</tr>
<tr>
<td>All</td>
<td>1,739</td>
<td>-</td>
<td>429</td>
<td>2,168</td>
</tr>
</tbody>
</table>

Notes:
\(^a\) From Productivity gain assuming an 8 hour day in Table 3.
\(^b\) A representation of the increase in capacity of an existing project inspector workforce in terms of full-time inspectors. Calculated by: column 1 x column 2
\(^c\) Sum of column 1 and column 3.

Data Quality
Project inspectors using the mobile technology solution collected and shared an average of 2.0 times more inspection information (Table 5), and all observations contained time/location metadata. For all DOTs the number of photo observations went up dramatically and the number of weather observations increased as well.

Transcription, Duplication, and Devices
Compared to the legacy process, the mobile technology solution software integration eliminated the transcription and duplication process involved in creating inspection reports. Also, project
inspectors no longer had to carry separate devices to take inspection photos and videos, nor did they have to manually upload associated files.

More Varied and Numerous Observations
The mobile technology solution showed a larger variety of observation types compared to observations collected using legacy agency practice. Increase in the use of photo observation was a trend observed throughout all three DOTs. A composition analysis of observations shows that, on average, photo observations accounted for 33% of the observation collected on a typical day, which is a significant increase over legacy methods that did not include photo observations directly into the reports.

Data Completeness
Inspectors using the mobile technology provided more complete data as it automatically captured the date, time, and location of each observation entry. The results of a metadata analysis indicated that the legacy process often missed time/location information of such information was imprecise.

Data Consistency
The consistency of the inspection information improved in two ways for inspectors using the mobile technology: (1) automated inclusion of inspection information eliminated the potential for inspectors to record incorrect information, and (2) the elimination of duplicate information across legacy data sources (e.g., photo and video files, daily reports, observations).

Data Availability
The mobile technology improved the timeliness of report submissions. Additionally, the mobile technology improved the timeliness of inspection information availability over the legacy processes by enabling project engineers and management personnel to access real-time inspection observations collected throughout the day on each active job site. Although harder to quantify, data stored via the mobile technology is available in one central database, is secure, and is readily searchable (e.g., by project, observation type, time, location, project inspector, etc.).

Timely Inspection Reports
In the interviews, project engineers and management personnel identified inspection reports as their primary source of inspection documentation using the legacy process. Timeliness of inspection reports created before the pilot project using legacy processes was inconsistent and depended on how busy the project inspector was at the end of the day. In some cases, project engineers shared that it can take anywhere from 2 to 3 days to 2 to 3 weeks to obtain the reports.

Information Availability
In the interviews, project engineers and management said with the legacy processes they either relied on the time-late project daily report for project information. If information was needed immediately they commonly called a project inspector onsite or visited the site themselves. Viewing a project inspector’s notebook typically involved locating the inspector (who often has the notebook on the project site), or, if it was available, was inefficient due to some of the content being hard to read.
Centrality, Security, Searchability
The mobile technology solution automatically integrated and stored all inspection information in a secure central repository that allows complete searchability within each DOT. Uploading information from the field and storing information in a central repository allows DOTs to retain all collected information even in cases when the mobile client is lost or damaged.

Examination of the legacy agency practice indicated that information from the project inspector’s field inspection notebook, photos and other media, and inspection reports were all stored in different locations. The field notebooks were typically in the inspector’s possession, photos and other media were typically shared via email or through a shared network drive, and inspection reports were accessible in the agency’s document management system.

Workforce Multiplier
A key component to collecting project inspection information with the mobile technology solution is that this same data and information can be leveraged by other divisions within a transportation agency for their respective functions as well. For example, a project inspection observation may photo document a drainage asset and its placement. That observation will be automatically time and location stamped, can be correlated to the bid item, and its prefabricated inspection information can be tied in as well using the mobile technology’s QR code functionality. This can be valuable information that asset management, environmental, and maintenance divisions can leverage for their respective functions. Tools like this, if applied properly, can enable the “collect once, use many” strategy that has the potential to benefit additional transportation agency divisions beyond construction in their respective functions throughout the lifecycle of the infrastructure assets the agency owns and provides for the traveling public.

Conclusions and Recommendations
This paper describes a pilot project that measured how mobile technology can be used to improve DOT project inspection. The pilot project compared the existing legacy project inspection process with the mobile technology solution for three DOTs (WSDOT, MnDOT, and TxDOT). Three general outcomes were compared: productivity, data quality, and data availability. While the scope of the pilot project was limited to State DOT construction inspection processes, the outcomes measured and conclusions drawn may very well apply more broadly to (1) different owner agencies (such as cities, counties, toll authorities, etc.) and private companies engaged in transportation infrastructure construction, (2) aspects of construction inspection not quantified in this pilot project, and (3) the general process of monitoring, managing, and improving transportation infrastructure construction. Conclusions based on this paper’s analysis are:

1. **Project inspectors using the mobile technology solution significantly increased their productivity without increasing their work hours.** Completing inspection reports, reduced travel time, and searching for information using the mobile technology solution provided an average overall time savings of 1.60 hours per day per inspector.

2. **Project inspectors using the mobile technology solution collect more and a larger variety of inspection information.** Project inspectors collected and shared 2.0 times more observations while significantly increasing the number of photo, video, and weather observations. This contributes to a more complete record of the project that can provide value to the owner agency.
3. **Project inspectors using the mobile technology solution provide more complete and consistent data.** All mobile technology observations are tagged with time/location data, and inspector daily reports are automatically generated from daily observations eliminating omission and transcription errors. Also, information that is often duplicated across legacy data sources is eliminated.

4. **The use of mobile technology improved the timeliness of inspector daily reports.** Compared with legacy processes, the mobile technology solution provided substantial improvement in submission rates within 24 hours (55% improved to 81%) and within 72 hours (73% improved to 92%).

5. **The mobile technology solution enabled improved accessibility of inspection information throughout the project office.** Compared to legacy processes, the mobile technology solution improved the timeliness of inspection information availability to project engineers and management by enabling real-time access to inspection information collected throughout the day on each active jobsite.

6. **The mobile technology solution provided data centrality, security, and searchability.** Compared to legacy processes, mobile technology information was automatically integrated and stored in a central repository and improved the accessibility and searchability of the information within each DOT.

7. **The mobile technology solution is a substantial workforce multiplier.** This is true based on productivity, data quality, and data availability. Based on measured productivity gains it can provide about a 25% workforce multiplier. Across the three pilot project DOTs this could result in the existing workforce (1,739 project inspectors) performing as if they were 2,168 project inspectors (a virtual gain of 429 project inspectors). Based on data quality, the mobile technology solution enables more varied and numerous observation (with significant increases in photos and weather data), provides better data completeness (more time/location information), and provides better data consistency by eliminating duplication and transcription errors/inconsistencies. Based on data availability, the mobile technology solution improved daily report timeliness, and provided real-time information access to project engineers and management.

Recommendations for future work include:

1. **Include remaining project inspector job functions in research scope.** The pilot project was limited to project inspection daily reports and field observations. Further benefits can be evaluated by expanding the function of mobile technology to encompass the entire project inspection business practice.

2. **Examine the value mobile technology provides in improving agency decision making.** Further investigate into how data quality and availability improvements affect real-time decisions made by project engineers and other office personnel may show impacts not observed in this pilot project. These impacts may be short-term (e.g., change orders or requests for information processing), or longer term (e.g., claims management).

Finally, this pilot project showed substantial, quantifiable gains when the mobile technology solution was used in place of legacy processes for WSDOT, MnDOT, and TxDOT. However, those gains could be even more if mobile technology is fully leveraged for its unique capabilities. During this pilot project the mobile technology was used to duplicate existing legacy processes without regard for their differing value and utility once they are converted to a mobile
technology. In other words, the mobile technology’s utility and value was somewhat stunted by only using it to duplicate legacy processes. As we have seen in other technology sectors (e.g., internet search, mobile phones) the true value of such step jumps in technology is realized when designers and users become more familiar with the full capabilities of such technologies and begin to understand new uses and provide useful information that was never dreamt of with legacy processes.

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