Project Inspection Using Mobile Technology — Phase I

An investigation into existing business processes and areas for improvement using mobile technology

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WSDOT Research Report

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16. ABSTRACT:

As mobile technology becomes widely available and affordable, transportation agencies can use this technology to streamline operations involved within project inspection. This research, conducted in two phases, identified opportunities for process improvement using mobile technologies and measured the outcomes from incorporating mobile tools as a part of project inspection work. The research also identified additional factors to characterize the use of mobile tools for project inspection.

The research approach focused on measuring three main projected outcomes, which include productivity, data quality, and data availability. Additional characteristics were observed to evaluate other aspects of using mobile tools for project inspection, in particular as it relates to recommendations toward how an agency may approach deployment of mobile technology. A pilot program was established where a mobile technology solution was used via field trials to measure these outcomes.

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Mobile Tools for Project Inspection

Executive Summary

Transportation agencies are confronting some important problems as they try to identify how to make the best use of their limited budgets. A key opportunity to identify time and cost savings is to look for potential improvements to business processes. This research examined the business process of project inspection, with a focus on the impact that mobile technology can have on workflows and decision making.

The research approach incorporated specification analysis, field documentation, and information gathering from 32 participant interviews with agency personnel, including field inspectors, project engineers, and management. Based on the results of this investigation, the report concludes that project inspection would improve significantly with appropriate mobile tools. While the information obtained through project inspection is highly valuable, it is not always captured efficiently or communicated effectively. Inspectors spend a substantial portion of their time on activities that could be streamlined with mobile technology.

Overall, inspection personnel are comfortable using technology as part of their work and would welcome a mobile device such as a tablet that could help them with their responsibilities. They identified a number of features and capabilities that would improve their work processes, including image capture, email correspondence, quick response (QR) codes for materials, real-time notifications and updates, and importing weather information. Specific needs were also identified with respect to access to project reference information, communication of inspection data, and connectivity in the field. Providing tools to support inspectors in the field would allow them to collect important data more frequently and reliably and better disseminate it throughout the organization.

Projected outcomes from incorporating mobile tools as part of project inspection work include significant time and cost benefits (31% productivity gain), improvements in data quality (50% more complete and consistent data), and benefits from faster and wider availability of project inspection data. The savings would come from increased inspector productivity and effectiveness. Inspection data would be more comprehensive as well as more reliable, and its ready availability would allow the data to be incorporated quickly into other agency processes.

The research findings from this investigation indicate that along with inspectors in the field, project engineers and managers would also benefit from these potential improvements. Mobile technology with appropriate features would address challenges with gathering and sharing data, thus expediting decisions and allowing agencies to act based on better, more complete information. As a result, it is recommended that this research continue into a second phase focused on testing these mobile features in use for project inspection in the field and quantifying the impact of their use. The results of this pilot test would help determine the feasibility of the projected outcomes and indicate whether agencies should move ahead with wide-scale deployment of the tools for their inspection workforce.

Introduction

Budget constraints and the current financial climate have motivated transportation agencies to look for ways to streamline operations to work more effectively with limited resources. WSDOT, for example, is implementing Lean principles across multiple initiatives within its organization. In order to enable changes to this end, proper tools must be made available to facilitate efficiencies where large opportunities exist for improvement.

One such opportunity exists within the function of project inspection for road owning transportation agencies. This research explores the business process of project inspection within state departments of transportation (specifically WSDOT and TxDOT) and how widely available and affordable mobile technologies (such as tablets) can be used as a tool to streamline this process and make useable the information that is generated and demanded during inspection in the field for the DOTs.

Research Objectives

The purpose of this State Pavement Technology Consortium (SPTC) research project evolved to examine the project inspection business process at the state transportation agency level, identify opportunities for improvement using mobile technologies, recommend an approach to achieving that improvement, and piloting the recommended approach while measuring the outcomes of the new process. The goals of this research are:

1. Examine the business process conducted for project inspection within WSDOT and TxDOT
2. Identify high impact opportunities for process improvement using mobile technology
3. Define the potential outcomes and their value to the transportation agency
4. Recommend a practical approach to achieve those potential outcomes
5. Define activities for a pilot program to be conducted in Phase II of this research project

Background

The following section presents key definitions and concepts related to the discussion contained within this report.

Project Inspection

The scope of project inspection considered under this research report corresponds to inspection of state transportation agency highway construction and maintenance projects. This includes inspection of all bid items and project activities DOT project inspection personnel are responsible for in the field during active construction and maintenance projects. Examples of such elements include pavement construction, traffic control, bridge construction, noise walls, work zone safety practices, guard rails, signage, electrical, and earthwork.

Mobile Technology

Mobile technology within the scope of this research refers to both hardware and software that can be used in the field to access and gather project related information. The hardware specifically consists of widely available tablet based computers that contain features such as touchscreens, GPS hardware, built in cameras, cell and wi-fi connectivity, accelerometers, among other core hardware features. Examples of commercially available tablets include the Apple iPad (iOS) and Samsung Galaxy Tab (Android). Hardware costs can range from $199 to upwards of $899 per tablet.

Figure 1. Tablet example.

Mobile technology also refers to the software that runs on tablet hardware enabling project inspection specific information to be referenced, collected, and seamlessly stored and/or uploaded from the field in both connected and disconnected environments.

Research Approach

A broad, qualitative research approach was taken to examine the business process of project inspection. Research and analysis were conducted at both WSDOT and TxDOT, which helped to validate the findings involving common issues with broad potential implications, rather than being agency-specific phenomena. The following components were analyzed:

- **Specification Analysis** – Read and analyzed construction specifications for WSDOT and TxDOT, as well as examples of special provisions, in order to understand the requirements for construction, the information needed in the field by inspectors, and the measurements/data/information project inspectors collect while inspecting a project. As construction specifications are extensive, the research focused on asphalt construction projects to get a sample of characteristics from specification documentation.

- **Field Documentation Analysis** – Analyzed field documentation for the data and information project inspectors gather while on a project site (Inspector Daily Reports, Daily Work Records, Field Note Records). Examples of the documentation helped give an idea of the scope of data collected in the field.

- **Audience Interviews** – Conducted interviews with DOT personnel including Inspectors, Project Engineers, and Management to understand project responsibilities, how information is gathered, how information is shared with different audiences, and how it is used. The interviews addressed issues and challenges such as the presence of information bottlenecks, what kinds of challenges agency personnel identify, where opportunities for mobile technology exist to support the process, and if agency personnel are comfortable using such technologies. The most significant proportion of effort was dedicated to this component of the Phase I research as learning what information agency field personnel and project level decision makers need is central to this research.

Consideration of these components provides a valuable picture of the various criteria involved in inspection of DOT projects, how information is collected and used in the field, and the roles of different DOT personnel within project responsibilities. Additionally, the interviews were particularly important to identify where needs for process improvement exist, whether mobile technology is the correct tool for improvement, and the likelihood of adoption and acceptance for a mobile technology solution if provided.

Specification Analysis

Specifications were examined to document examples of requirements prescribed by DOTs for state projects. These are attributes that project inspectors check while in the field and document to ensure that work being done complies with project requirements.

To get a sample of attributes, asphalt project specifications for both WSDOT and TxDOT were analyzed. Though this is only a subset of the many items project inspectors examine in the field, it gives a representation of the type, detail, and variability of information needed and collected in the field. Additionally, understanding the commonality and distinction between states is vital to identifying where the broadest business process improvement opportunities exist.

To this end, the research team extracted common attributes and compared them between WSDOT and TxDOT to see how specification requirements vary between state DOTs. The following table presents the results of this comparison:

Asphalt Specification Requirements

Attribute	WSDOT	TxDOT
Tack coat	1. A tack coat of asphalt shall be applied to all paved surfaces on which any course of HMA is to be placed or abutted. 2. Tack coat shall be uniformly applied to cover the existing pavement with a thin film of residual asphalt free of streaks and bare spots. A heavy application of tack coat shall be applied to all joints. 3. For Roadways open to traffic, the application of tack coat shall be limited to surfaces that will be paved during the same working shift. 4. The spreading equipment shall be equipped with a thermometer to indicate the temperature of the tack coat material. 5. Equipment shall not operate on tacked surfaces until the tack has broken and cured. If the Contractor's operation damages the tack coat it shall be repaired prior to placement	Major construction related items • Preparation of surface – clean the surface before placing the tack coat. • Application rates - Unless otherwise approved, apply tack coat uniformly at the rate directed by the Engineer. The Engineer will set the rate between 0.04 and 0.10 gal. of residual asphalt per square yard of surface area • Apply a thin, uniform tack coat to all contact surfaces of curbs, structures, and all joints • The Engineer may use Tex-243-F to verify that the tack coat has adequate adhesive properties
Hauling	Loads are tarped when conditions or forecast for precipitation or temps <45 degrees	Tarp all loads (SS3268) End dump trucks only allowed in conjunction with remixing equipment or when Pave-IR system is used
Material transfer	MTV for top 0.3 ft of the pavement section in traffic lanes with a depth of .08 ft. or more	Windrow equipment must pick up substantially all the mix placed in the windrow Min. storage unit capacity 8 tons for remixing equipment
Paver	Certification from manufacturer, automation equipment	Automation equipment
Grade and slope	Transverse slope controller can maintain screed slope ±0.1% (GSP) Reference lines required for both outer edges of the traveled way for vertical control	Paver skis or mobile string line at least 40 ft. long
Rollers	Pneumatic tire rollers for wearing course after Oct. 1 and before Mar. 31	Vibratory rollers operated at speeds to achieve at least 10 blows per foot Individual tire inflation pressures on pneumatic rollers within 5 psi of each other

Attribute	WSDOT	TxDOT
Aggregate gradation	Price adjustment factor for HMA mix based on sieve size • Factor=2 for 1-½", 1", ¾", ½", ⅜", and No. 4 sieves • Factor =15 for No. 8 sieve • Factor=20 for No.200 sieve • Factor=40 for asphalt binder • Factor=20 for air voids	N/A
Lots and sublots	Max 15 sublots per lot, can be increased to 25 for final lot Max mix design sublot size of 800 tons Max density sublot size of 80 tons, up to 120 tons for final sublot of the day (option in GSPs to increase these to 120/180 or 160/240)	Lot 1=1,000 tons Subsequent lot sizes from 1,000-4,000 tons based on anticipated daily production Each "production lot" consists of 4 equal sublots, which when the mix is placed the area covered becomes the "placement lot", also with 4 sublots Incomplete lots when lot is begun but cannot be completed, such as last day of production
Test sections	600 – 1,000 ton test sections allowed at request of Contractor at beginning of paving GSPs indicate test section required for mix design >20% RAP	N/A
Sampling	Random sampling will be conducted in accordance with WSDOT Test Method T716. Frequency of one sample per sublot, sublots defined as uniform in size with a maximum size of 800 tons.	Obtain two 6-in. diameter cores within one working day of time the sublot is completed 4-in. diameter cores allowed for Type D & Type F Visually inspect that current layer is bonded to underlying layer
Temperature Segregation	N/A	Obtain a thermal profile for each sublot Temperature differential >25°F will be deemed as having thermal segregation Suspend operations if max. temp. differential >50°F
Density	Composite Pay Factor (CPF) not less than 0.75 using 91% of reference maximum density Low cyclic density: • Spots or streaks less than 90% of reference maximum density • $500 price adjustment for any 500-ft section with two or more readings below 90% • $200 price adjustment for a sublot if one density reading at	Min. 1 profile per sublot to start, reduce to 1 profile per lot if 4 consecutive profiles within tolerances, resume 1 profile per sublot if a profile fails Maximum allowable range (Highest to lowest) • Range of 8.0 pcf for Type A & Type B • Range of 6.0 pcf for Type C, Type D & Type F

Attribute	WSDOT	TxDOT
	either longitudinal joint is below 90%	Maximum allowable range (Average to lowest) • Range of 5.0 pcf for Type A & Type B • Range of 3.0 pcf for Type C, Type D & Type F
Longitudinal joints	The project engineer will evaluate the HMA wearing surface for low density at the longitudinal joint in accordance with WSDOT procedures. Low density is defined as less than 90.0-percent of the reference maximum density	Density no more than 3.0 pcf below density at or near center of mat Evaluate pavement edge that is or will become the joint for each sublot
Surface smoothness	Wearing course shall not vary more than ⅛” from 10-ft straightedge placed parallel to centerline Transverse slope shall not vary more than ¼” in 10 ft from rate shown in plans Deduct $500 from each 100-ft section of a single traffic lane that deviates (GSP) Corrective action for high spots more than ⅛” in 10 ft, IRI values >95 in. per mile, corrective actions not to reduce pavement thickness more than ¼”	Transverse profile shall not vary more than ⅛” from any two contact points on 10-ft straightedge Longitudinal profile is tested using high-speed or lightweight inertial profiler • Acceptance and pay adjustment using schedule based on average IRI • Instead of requiring corrective action, Engineer may assess $3,000 penalty per 0.1-mile section that is deficient or has localized roughness
Weather conditions	No wet surfaces Written approval from Project Engineer after Oct. 1 and before Mar. 31 Minimum surface temperature • 55°F for wearing course less than 0.10 ft compacted thickness • 45°F for wearing course between 0.10 and 0.20 ft • 35°F for wearing course more than 0.20 ft • 45°F for other courses less than 0.10 ft • 35°F for other courses above 0.10 ft • 50°F for asphalt prime coat	(SS3268) If using Pave-IR, may pave anytime roadway is dry and surface temp. >32°F If not using Pave-IR, min. surface temp. depends on binder grade • PG 64 or lower - 45°F (subsurface or night paving), 50°F (surface layer in daylight) • PG 70 - 55°F (subsurface or night), 60°F (surface layer in daylight) • PG 76 or higher - 60°F for all layers • Values may be lowered by 10°F for warm mix or if using equipment to eliminate thermal segregation (MTV?) • No more than 10°F of thermal segregation

Table 1: Comparison of attributes between WSDOT and TxDOT asphalt specification documents

This comparison between the two states' standard specifications showed relative overall consistency between the categories of required attributes defined and measured in both states (both states, for example, have specified requirements for "longitudinal joints"). Variability was more frequently identified between the specific requirements within each attribute category. For example, the minimum surface temperature requirements for paving different layers were defined in part based on thickness in Texas, and based on binder grade in Washington.

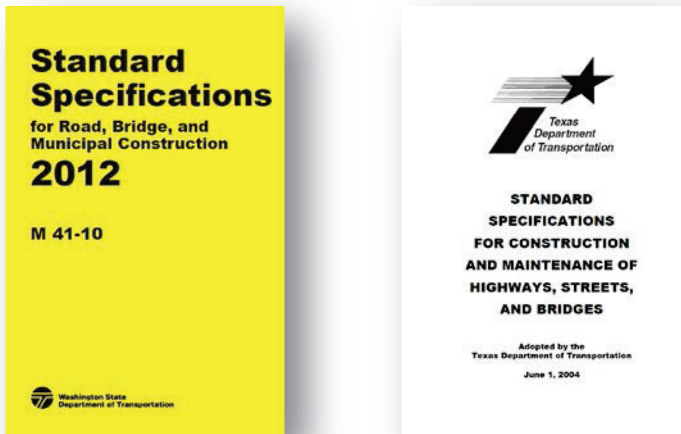

Figure 2. Cover pages of WSDOT and TxDOT Standard Specifications.

From the business process perspective, this indicates that across the two states examined, there is commonality with respect to responsibilities and activities for state inspectors to document specification compliance[1] (as well as special provisions, and project plan requirements). With common business processes come common opportunities for efficiency.

The common ground between specifications indicates that the most essential data to collect for project inspection will be similar in type across agencies. This makes it possible to conceive of a core framework that could serve the overall inspector workforce. The differences between individual requirements and parameters for different agency specifications can be addressed by adapting that framework to the particular specification. For technology to support the business process of inspection data collection, the tools must be customizable to agency needs while providing the overall framework of information.

Field Documentation Analysis

DOT Project Inspectors in both Washington and Texas are required to produce documentation in the field to record project-related information. The purpose of that information is to communicate the facts of what transpired on the job site that day, which serves to answer two main questions:

[1] There are contract types where this responsibility falls more heavily on the contractor, but for the purposes of this research, the focus will be on the role of DOT personnel for project inspection.

1.) Are activities, materials, and results in accordance with the plans, specifications, and general quality standards? (this includes such things as safety, traffic control, materials, construction practices, equipment, personnel, environment, weather, etc.)
2.) For what pay items does the state need to pay the contractor?

In both states, project inspectors are required to fill out daily reports of activities in the field. In Washington state, these forms are called Inspector Daily Reports, or IDRs. In Texas, they are referred to as Daily Work Records, or DWRs. In both states, they perform essentially the same function. That is, they are to be a "dispassionate record of what transpired in a day", objectively documenting project related activities including items such as the following:

- Basic form data
    - Contract number
    - Day and date
    - Sheet number X of Y (for paper forms)
- Signature block
    - Name of inspector
    - Inspector signature
    - Reviewer signature
- Time
    - Reference items
        - Time inspector arrives at site
        - Time work begins
        - Time work ends
        - Time inspector leaves site
    - Inspection log
        - Generally, all recorded items are given a time notation (precision level is 5-minute granularity)
        - Changes in construction activity
            - Stops and starts
            - Other changes to procedure
        - Time when a problem is first observed
        - Communications with contractor
        - Time when problem is resolved
- Location
    - Station where work starts for the day
    - Station where work ends for the day
        - For construction on multiple lanes, need option to include more than one location as starts and stops may not be the same
    - Location where problems are identified

        - Depending on the issue, may be begin and end positions (equipment was not working properly from X to Y) or specific locations (improper alignment at A, B, and C)
- Weather
    - Generic WSDOT form includes space for weather description, broken up into AM & PM
    - WSDOT asphalt paving form calls for specific temperatures
        - Min. and max. air temperature
        - Min. and max. temperature at surface
- Operations
    - Document information about the day's operations and project progress
- Contractor
    - Identification of general contractor, possibly subs if relevant
    - Name and title of contractor representative
        - When reporting communications, representative should be identified by name
        - Work crew personnel may be identified by role
    - Generic WSDOT form has space for contractor's workforce, including number of crew and hours worked in a number of categories
    - Discussions with contractor
    - Orders given and received
    - Personnel on the jobsite
- Equipment
    - Identification of major equipment
        - Description
        - Specifics about particular parts logged when malfunctioning or observed in an inspection issue
    - Operating times
    - Idle times
    - Min. and max. speed (where appropriate, for example paver speed)
    - Equipment specific information (for example, pneumatic roller tire pressure)
- Materials
    - Plan quantity
    - Estimated quantities placed
        - Pavement mix (tons)
        - Sq. yds. of surface paved between marked stations as well as daily and running totals
            - Level of detail, for example, WSDOT asphalt paving form distinguishes base, leveling, and wearing courses as well as tack coat
    - Note failing test results
- Traffic control
    - Traffic control plan, work zone traffic control, and current flagging card for flaggers and spotters

    - Note incidents or accidents
    - Note changes in operations that require additional lane closures
- Environmental Information
    - Document environmentally sensitive areas on project site
    - Document and report personnel if in environmentally sensitive area

Additionally, project inspectors are tasked with having to collect information on contract related pay items. This includes such things as:

- Material quantities
- Bid items completed
- Calculations for pay notes
- Daily work quantities
- Locations of materials deliveries and work performed

In Washington State, for example, the DOT uses a form called a Field Note Record (FNR) to collect and communicate payment related information from the field personnel to the office personnel for processing.

Documentation Observations

Standard forms along with examples of completed field documentation were reviewed to assess what data inspectors collect in actual practice. From reviewing the small sample of IDRs, DWRs, and FNRs received, a few main characteristics and impacts stand out. One is the abundant variability in the type of data being collected from one form to the next, depending on the project and type of activity. At the same time, certain standard information needs to be documented in the reports in order to track compliance with plans and specifications.

The impact of this is that the forms are designed for very free-form data collection, providing mostly plain-text input for inspectors aside from tracking basic project information. This has both benefits and drawbacks. The benefits include being open to any information the inspectors need to record from the perspective of capturing data and observations. It also provides flexibility for different styles of recording data or taking notes from one inspector to another. When a substantial narrative description is needed or an unusual combination of elements is involved, this approach allows inspectors to enter information in a way that might not fit in a form that is too restrictive.

On the other hand, some of the data collected in this fashion may be lacking consistency or structure. Inspectors may record similar observations in different formats, or they may include or leave out elements that another inspector would capture. This increases the variability in the documentation and could create difficulties when attempting to track down information needed in the future. For example, trying to correlate problems observed across a project by different inspectors, or covering multiple projects, could pose a challenge. In addition, no standard method emerged using the current forms for notating or highlighting issues that need resolution or further attention.

The key for data collection is finding a balance between structure and flexibility, whether the documentation tool being used is a paper form or a mobile tablet device. One of the potential advantages of a technological solution is that it offers the possibility of switching back and forth more easily, providing more structure or greater flexibility at different times as appropriate. In this way, inspectors can have the freedom to record anything that should be documented at any time, while the tool can ensure that essential information is captured easily and accessibly.

Based on an examination of the existing requirements for documentation that inspectors work toward, these data collection needs create an opportunity to automate input for a subset of this data. For example, location information is currently specified manually (typically using station and offset) within the current forms. Using a tablet computing device, GPS information is readily available and can be imported automatically by an inspector's button click in the field[2]. Time logging, weather information, and recurring project information can be auto-populated and presented to the inspector, who can then confirm and record it rather than gathering and recording the information from scratch. In addition, photo and video content could be gathered in a seamless way to provide immediate, objective information that can be included directly within the project records.

Audience Interviews

A major portion of the research efforts included conducting audience interviews with employees from both WSDOT and TxDOT. These interview participants are all agency employees that perform different project-related roles within the DOT.

The audiences were broadly categorized into 3 main groups (based on project-related responsibilities):

- Project Inspectors
- Project Engineers
- Management

Each of these groups can be further differentiated according to organizational hierarchy as outlined in the table below. Some variance between job titles also exists, both across the participating DOTs and even within the same DOT, from one project office to another. In order to employ standard nomenclature for this report, a naming convention will be used as follows:

[2] GPS accuracy varies between tablet hardware. Accuracy constraints provided by less costly commercially available tablet hardware to be assessed in phase II vs. more costly survey-grade GPS. External gps hardware can be connected to tablet hardware as required.

	Report Title	Description	WSDOT Title	TxDOT Title
	Technician	Performs materials testing and gather samples in the field. Works between multiple jobs where needed. Reports to Chief Inspector.	Technician	Tester
Project Inspectors	Project Inspector	Individual who is responsible for performing inspection on projects in the field. This individual does not manage others and is typically the personnel resource dedicated to 1 active project in the field at a time.	Inspector / TE2	Field Inspector
	Chief Inspector	Manages multiple inspectors and multiple jobs. These individuals are a resource for Project Inspectors when assistance is needed. They roam between multiple projects at a time.	Chief Inspector / TE3	Project Manager
Project Engineers	Assistant Project Engineer	Assists the Project Engineer and plays similar role to Project Engineer, sometimes asked to handle a subset of the responsibilities of the PE at the project field office.	Assistant Project Engineer / TE4	Assistant Area Engineer
	Project Engineer	Head of field office. Ultimately accountable for all project related activity occurring through that field office.	Project Engineer / TE5	Area Engineer
Management	Managers	Personnel not within a particular field office, but these individuals are involved when items are escalated or conflict resolution is necessary. Titles range here, from State Construction Engineer to Construction Section Director to Assistant Regional Administrator.	Varies	Varies

Table 2: DOT personnel interviewed during research

The organizational hierarchy of the project offices within the DOTs studied is typically configured as outlined in the following diagram.

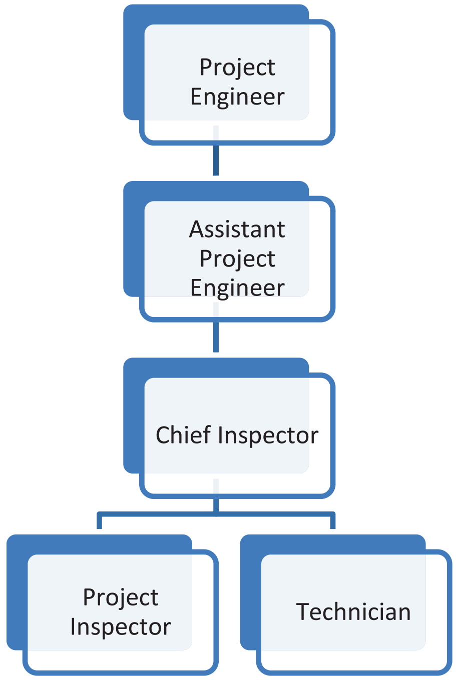

Figure 3. Organizational chart for DOT project offices.[3]

From the project offices, when issues need to be escalated, they report up to the regional offices (called "districts" at TxDOT), and from the region, they escalate issues up to the DOT headquarters.

TxDOT has 82 area offices in 25 districts. WSDOT has 33 project offices in 6 regions.

The approach taken for this research included conducting interviews with a representative sample of DOT personnel from both DOTs in the roles described above. Interviews were conducted with a total of 32 employees from WSDOT and TxDOT. The following table enumerates the personnel groups and participant counts for the interview efforts:

Role	Total
Project Inspectors	22
Project Engineers	6
Management	4
Total	**32**

Table 3: Breakdown of interview participants

The interviews were structured as 1-on-1 conversations and took approximately 1.5 hours to conduct, consisting of a set of questions matched to the 3 major role categories: Project Inspectors, Project

[3] At TxDOT, project offices are called Area Offices, and they have another step of hierarchy called a Construction Manager between the assistant area engineer (project engineer) and the project manager (chief inspector).

Engineers, and Management. The interviews were designed using a set of questions to guide conversational interactions with participants. The questions were aimed at generating information about each participant's role with respect to DOT projects, what information is collected in the field and used in their roles, with whom the participants interact in their positions, what work activities they spend their time on, what challenges they identify for their respective roles, and what their comfort level is with technology. The summation of these information categories painted a valuable picture of the opportunities that exist for meaningful business process advances by leveraging mobile technology.

Audience Interview Response Summary

General Responses

The following tables are collected responses for general information provided by all interview participants (Project Inspectors, Project Engineers, and Managers).

How long have you been/were you in this role? (in years)	
Minimum	4
Maximum	31
Average	16.25

Table 4: Summary of participant experience (in years)

What percentage of your time do you spend in the field?			
Role	**Min**	**Max**	**Average**
Project Inspector	70	100	90.33
Chief Inspector	20	90	51.43
Project Engineer	5	50	14.29
Manager	5	25	15.00

Table 5: Summary of participant time spent in the field during construction season

Project Inspector Responses

The following tables cover role-specific information provided by the Project Inspectors interviewed.

How much time to do you spend inputting information into the computer?			
Inspectors	**Min**	**Max**	**Average**
Hours per day	1.00	4.00	1.88
Percentage of time	12.50%	50.00%	23.44%

Table 6: Summary of participant's daily time expenditure inputting information into the computer

How much time do you spend looking up information in specifications, plans, and construction manuals during a typical day?			
Inspectors	**Min**	**Max**	**Average**
Hours	0.5	4	1.51
Percentage of time	6.25%	50.00%	18.93%

Table 7: Summary of time spent daily by project inspectors searching for project information in project related documents

How much time do you spend doing calculations in the field?			
Inspectors	**Min**	**Max**	**Average**
Hours	0.5	6	1.65
Percentage of time	6.25%	75.00%	20.63%

Table 8: Summary of time spent daily by project inspectors performing calculations in the field

What are the most challenging parts of your job? (Most typical responses)	
Challenge	**Response %**
Sending and uploading pictures	55%
Connectivity in the field	50%
Documentation of claims and change orders	50%
Time needed to enter information	45%
Materials documentation	45%
Communication, coordination, correspondence	32%

Table 9: Most frequently mentioned responses from project inspectors when asked about the most challenging parts of their job

Project Engineer Responses

The following tables are compiled information provided by the Project Engineers interviewed.

What percentage of your time do you spend reviewing inspectors' reports?			
Engineers	**Min**	**Max**	**Average**
Hours	0.0	2.5	0.95
Percentage of time	0.00%	31.25%	11.88%

Table 10: Summary of time spent daily by project engineers reviewing inspector daily reports (IDR, DWR)

What are the most challenging parts of your job? (Most typical responses)	
Challenge	**Response %**
Documentation of claims and change orders	100%
Communication, coordination, correspondence	86%
Sending and uploading pictures	86%
Materials documentation	43%
Time needed to enter (or review) information	43%
Staff training	29%

Table 11: Most frequently mentioned responses from project engineers when asked about the most challenging parts of their job

Technology Responses

The following table represents the technology-related questions asked of all participants to better understand their comfort and familiarity with using technology.

Technology Related Questions		
Question	Yes	
Do you use a computer at work?	100.0%	
Do you own a computer at home?	100.0%	
Do you have a smartphone?	64.52%	
Do you have a tablet?	38.71%	
Have you used a tablet before?	67.74%	
Would you be comfortable using a tablet if one was provided for work?	Min	2.5
	Max	5.00
scale of 1 (not at all) to 5 (totally comfortable)	Average	4.60

Table 12: Summary of technology related questions

Notable response trends	Total %
Commented on the importance of photos	86%
Responded negatively to the question, "Do you think you could save time in the field by using technology?"	0%

Table 13: Notable response trends identified during interviews

Noteworthy Specific Responses

Value of Inspection Documentation

Interviews were conducted with the assurance of anonymity to illicit genuine responses from the participants.

> *"This picture is worth $100,000." – Person 18, WSDOT*
>
> *"Time goes on, bids get lower and lower, claims get higher and higher. Some contractors bid to break even, then submit claims to make their money. The more documentation we have, the better off we're sitting" – Person 13, WSDOT*
>
> *"$198k in change order, through my documentation, they went through, they [contractor] were due about $100k that they could come up with, so they settled for $130k. [With] no documentation, they would have nothing to stand on." – Person 13, WSDOT*
>
> *"Proper documentation is very key. 80% of their job is documentation, 20-30% is inspection". – Person 14, WSDOT*
>
> *"So much liability with everything we do" – Person 13, WSDOT*
>
> *"There is no such thing as over documentation." – Person 17, WSDOT*
>
> *"A completely filled out IDR is my best answer to 99% of questions. Anything that can make it easier for them [project inspectors] to fill out as they are going along during the day." – Person 16, WSDOT*
>
> *"Photographs are more accurate, factual". – Person 20, WSDOT*
>
> *"Some things you think that aren't important can be important later in the game." – Person 1, TxDOT*
>
> *"Can't write too much, but you can write too little" – Person 1, TxDOT*

Challenges w/ gathering proper documentation/media

"Work 10-12 hours, drive home for 2, do you really want to be sitting in your truck or docking it [laptop computer] for another 20 minutes just to get a picture on a server?" – Person 10, WSDOT

"Managing information is a challenge." – Person 16, WSDOT

"Tag email by a project? That's all I've ever wanted."   – Person 21, WSDOT

"Some folks spend 4 hours a day behind the computer inputting information" – Person 5, TxDOT

"Last year, on paper I inspected, but didn't write in the computer…got called off to something else, I forgot to write down equipment being used. They [contractor] put in claim for extra equipment. I went back to the scrap [of paper], and later I was able to add it back in." – Person 15, WSDOT

Time Expenditure

On looking up spec info on a mobile tablet instead of laptop or paper. "I could save a good 2-3 hours a day!" – Person 5, TxDOT

"When I'm on overtime, they're paying me $50-$60 an hour, 4 hours of overtime at end of week, and I'm going to do that for next 10 weeks …" – Person 10, WSDOT

"Not enough money to keep system at service level, which creates a lot of stress." – Person 21, WSDOT

Finding Documents and Media

"That's a million dollar piece of paper." – Person 1, TxDOT

"Very important and very time consuming to go back and dig up records". – Person 9, TxDOT

Value of Information Sharing and Availability

"Real-time info from the field would be great. With a dwindling crew and bigger workload, that information is important" – Person 14, WSDOT

In reference to field information about a huge claim ($50M+). "If I could have that information, I could have stopped it." – Person 14, WSDOT

"Multiple people need access to the same information" – Person 18, WSDOT

"Happens weekly where I'll notice something [in pictures or documentation] that my guys don't." – Person 18, WSDOT

"Pictures help me tremendously. Everybody has to go out to the field without [them]..hours wasted." – Person 7, TxDOT

Referring to tablet-based solution - "Just like being in multiple places at once" – Person 9, TxDOT

On reading IDRs. "I try to read them the next day. For every project, there are 5 x 20 = 80 to 100 IDRs when fully staffed. It would be helpful if they could flag certain issues and automatically send". – Person 17, WSDOT

On Real-time Information

"Bad news doesn't get better with age" – Person 18, WSDOT

Value of Mobile Technology

"Bid items that are NOT MOBILE (with a bridge project), allow you to go back to your office. Laptops work nice there. But when on a paver, work is moving down the highway" – Person 10, WSDOT

Completeness of Data/Data Integrity

"Somedays I just say 'Whatever, they're not going to get that information. It's not important enough as I'm trying to keep up." – Person 10, WSDOT

"Some days it can snowball on you and you have no time to get back to your truck" – Person 10, WSDOT

"Chronology/timeline is VERY important. Makes your argument a slam dunk" – Person 9, TxDOT

"Concrete didn't arrive until 8 p.m., but clearly he meant 8 A.M." – Person 16, WSDOT

Results/Discoveries

Examining the responses from the interview participants in more detail allows some important themes to manifest. These in turn reveal potential opportunities for the application of mobile technology solutions. Among the key trends identified were:

- The high value of the information collected in the field during the course of project inspections
- The importance of communicating project inspection information within the organization
- Important considerations with respect to how project inspection information is collected
- Field personnel needs for reference information relating to the project
- Significant time expenditures involved with inspector activities in the field
- Challenges routinely faced by inspectors as they go about their work
- High levels of comfort among the participants with technology as a means of addressing these issues

Overall, the interviews showed that project inspection can capture large volumes of information, but sometimes struggles with efficiency in collecting that information, or with organizing it so the information can be managed on an ongoing basis. Improvements in technology in the field would provide an opportunity to address these issues.

Value of Project Inspection Information

The information collected about projects through inspection activities is highly valuable, and significant resources are dedicated to it. Transportation agencies need clear, objective information from the field supported by suitable documentation. In order to ensure that projects get constructed according to plan, an effective inspection program must be in place.

Although inspection information can also be conveyed by face-to-face communication or telephonically, documentation is fundamentally important to create a record of what was inspected. Project inspection documentation should paint a clear picture of work progress, issues that arise on the job, conformance or non-conformance of construction and materials to plan, and payment for the contractor. These records need to be effectively collected, stored, and retrieved in order to be useful.

Some documentation, particularly when it relates to payment for items under contract, serves an immediate and obvious purpose. In other cases, the implications may not be apparent right away, but down the road the information can be worth tens of thousands, hundreds of thousands, or even millions of dollars. Large amounts can depend on one properly maintained element of information, if the documentation for it is retrievable.

In addition to closing out projects and addressing claims, inspection data may need to be retrieved at a later date for other purposes. For example, other offices within the DOT may want this information to help with cradle-to-grave accounting of assets.

Overall, the interviews reinforce the vital importance of properly collecting and maintaining documentation related to project inspection. Providing easy-to-use, effective tools for collecting project inspection information would add significant value to transportation agencies that depend on the data. Given the established worth of this documentation, targeted investment in technology to increase its impact would constitute a logical investment.

Communicating Project Inspection Information

Proper communication of project inspection information may involve some form of documentation, but in many cases a telephone call or face-to-face communication are also used. Both inspectors working in the field, as well as engineers and management personnel working in project offices, emphasized the key role of communication in their interviews. Many of them reported similar scenarios illustrating communication strategies and areas for potential improvement.

From the perspective of inspectors in the field, multiple project inspectors reported that they leveraged their personal smartphones in order to take photographs related to what they were inspecting, which they would then send via text message to their supervisors for review and input. However, many of these images were not necessarily saved to the project file or otherwise made easily accessible as part of the documentation associated with the project. Having communications tools that are more thoroughly integrated with the rest of the agency’s systems could help ensure that information communicated in this way was retained.

Having clear records documenting key communication is also important. Critical information and decisions may be covered in transient communications, such as telephone or face-to-face, for which a documentary record needs to be created. In other cases, the communication may have some form of documentation, ranging from electronic forms such as an email to old-fashioned handwritten notes scribbled on a pad. This documentation is not necessarily associated with other records, however, and may be challenging to retrieve later if needed.

From the point of view of those overseeing inspection activities, this represents a significant concern. Multiple chief inspectors and project engineers referenced first-hand experiences where issues could have been prevented, or financial liability for the DOT averted, if they had had direct access to comprehensive project inspection data on a real-time basis, or in a timely manner.

Project Inspection Information Collected

The details of what information is collected and how that information is collected play an important role in the impact of project inspection. Photographs are a crucial documentation tool and often help to provide clear, objective evidence of items that project inspectors record in writing. Videos can be helpful as well for capturing specific activities, or to effectively record things that exist in a larger context, such as traffic control setups.

Even with the value added by a visual record, capturing specific data points and observations is a core information collection task. More importantly, data frequently needs to be associated with other pieces of information collected, whether those are written observations, field measurements, or visual information. For example, location information is a key for many elements that are documented during project inspection. Similarly, time stamping can also play an important function in helping determine what it is that other items of documentation show.

All of these elements, from visual documentation to data and metadata, can be collected using currently available mobile hardware. There is a natural opportunity to integrate these elements specifically for the purpose of project inspection. Using mobile technology would make it possible to create a powerful field tool for the collection, documentation, and sharing of project inspection information.

Project Reference Information Needed by Field Personnel

While in the field, project inspectors need the capability to look up information as well as record it. Plans, specifications, special provisions, and construction manuals are items that inspectors indicate they are constantly referencing. This can amount to thousands of pages of documents that they need to have available. In most cases, they are or can be made available in electronic format.

Qualified Product Lists (QPL) are also important for inspectors to have access to in the field. This allows them to reliably determine whether the materials in use on the project are approved. When a contractor requests to use a particular material, if the inspector can look it up in the current QPL, this makes it much easier to approve or reject materials.

In addition to simply having access to this reference information, inspectors on the job site would benefit from additional features such as search and bookmarking. The ability to easily search these resources directly while on the job site will likely save inspectors substantial amounts of time. Instead of having to go back to the truck or office and dig through paper copies, being able to carry it with them in mobile electronic form would provide a significant benefit.

Time Expenditure

The question of how project inspectors spend their time is a critical piece of the puzzle in this research. This is where the focus should be placed when looking for ways to leverage tools and improve efficiency. Streamlining areas where personnel spend significant time will yield better outcomes than improvements on areas where little time is spent.

Not surprisingly, project inspectors reported that they spend the overwhelming majority of their time in the field. When breaking down their activities, some of the tasks they reported spending significant time on include the following:

- The average time spent entering information into the computer for project inspection personnel was 1.9 hours per day
- The average time spent looking for information while in the field was 1.5 hours
- The average time spent performing calculations in the field was 1.7 hours

Combining these three activities would indicate that inspectors are spending over five hours per day on these tasks, or 62.5% of an 8-hour workday. Additionally, many inspectors indicated that they regularly work longer days, but it is partly due to such time-consuming efforts that overtime becomes necessary.

These are all activities that properly designed computing tools can naturally assist inspectors with. This suggests that leveraging mobile technology offers an opportunity to help inspectors work more efficiently and make them more available for other important tasks that are part of their responsibility.

Challenges Identified

Participants identified a number of challenges that impede or disrupt their work. Many of these revolve around communication, documentation, and the difficulties involved when inspectors cannot observe project activities while simultaneously having access to the resources they need.

Although many aspects of the process for creating documentation have transitioned to an electronic format, documenting information while in the field remains difficult. Using a laptop in the truck can be cumbersome, and many participants also identified connectivity issues while in the field as a significant problem. Going back to the office to record documentation is time-consuming and takes inspectors away from the project activity they need to observe.

Project inspection information also needs to be timely, and many of these challenges have an impact on the ability to submit daily documentation as required. Communication, coordinating work, and managing information becomes difficult when not everyone is able to stay up-to-date on the state of a project.

Other challenges identified are technical in nature, such as the ability to send and upload pictures while in the field. Processes such as materials documentation present multiple challenges, both in terms of having access to the documentation in the field and in matching materials on the job site to the correct documentation.

Most of these challenges are amenable to some form of technological solution. Finding a solution that can help streamline the work of project inspection will create considerable value at all levels of DOT construction organization.

Technology Comfort

In general, interview participants reported a high level of comfort with the use of technology, both personally and as part of their work. All have at least a baseline familiarity with it, as 100% of those interviewed use computers in their respective roles at work, as well as for personal use at home.

With respect to mobile technology, a majority (65%) currently have and use a smartphone. The majority of participants (68%) also report that they have used a tablet before. When asked what their comfort level would be with using a tablet for work, if one was provided for them, the average response was 4.6 on a scale of 1 to 5, 1 being defined as “not comfortable at all” and 5 being defined as “totally comfortable”.

The responses lead to the conclusion that mobile technology is currently in use and has widely been accepted by individuals working for the participating DOTs. In planning for work on future projects, it is clear that DOT personnel would generally welcome work-related mobile tools. As already indicated, if properly designed these tools could help inspectors make better use of their time, document inspections more effectively, and reduce claims and disputes over projects. The interview participants confirmed these conclusions, as no participant when asked stated that technology could not help them save time in the field.

Conclusion

In order to tie the results and discoveries from the interviews together, some key conclusions can be reached about the value of project inspection information and the potential for process improvements. First of all, it is clear that project inspection documentation, information, and data are extremely valuable. Accordingly, a proportional effort should be made to facilitate collecting this information in a useful and efficient manner. Furthermore, the ability to share the information collected further amplifies its value.

To achieve significant process improvements, areas need to be identified that can offer a high return on investment. A logical place to start is to use technology to streamline processes where large amounts of time are currently spent as identified in this research. Another key focus should be on areas identified frequently by participants as challenges by providing appropriate tools and increasing capabilities to tackle these areas.

The potential to address these items exists using current pervasive hardware in the marketplace. Mobile technology using tablet devices can provide a base platform on which the tools and capabilities to improve inspection processes can be created. As these tools can be developed, deploying them should be accepted by agency personnel, as resistance to using this technology has effectively dissipated.

Overall, there is evidence of collective support at all levels (field personnel, engineers, and management) for the potential of mobile technology to improve project inspection processes. Specific capabilities are discussed in the next section.

Capabilities Ranking

Through the interview process, to meet the challenges identified, several ideas for solution capabilities were presented. Interview participants were asked to rank capabilities as they relate to solving the challenges that were discussed and identified. A value scale was defined between 1 and 5, where 1 was defined to mean “not useful at all” and 5 was defined to mean “extremely useful”.

Rank the following features (1 to 5, 1 not useful, 5 extremely useful):			
Feature	Min	Max	Average
1. Consistent, seamless image capture, allowing inspectors to write notes on image, compress, and upload easily	4	5	4.88
2. Relevant email correspondence can be tagged and saved along with project info	4	5	4.88
3. QR codes for materials acceptance or prefab components	4	5	4.88
4. Updates in real time, where items can be flagged immediately and notifications sent to directly those that need it	3	5	4.75
5. Automatically import weather data based on location (GPS or point on map)	3	5	4.50
6. Perform calculations automatically in the field for FNRs or IDRs	2	5	4.25
7. eSignatures for inspection or quantity reports	2	4	3.00

Table 14: Ratings given by participants to potential feature capabilities

The listed features and their potential benefits are explained in more detail below.

Image Capture

Consistent, seamless image capture, allowing inspectors to write notes on image, compress, and upload easily

Project inspection photos were identified through interviews as a critical information tool in support of project documentation. At the same time, interview participants identified a number of issues that make it difficult to manage photos effectively. Some of these challenges include:

- Large images take a long time to upload
- The inability to make notes directly on a digital photo, such as to highlight a particular aspect as reflecting good or bad construction practice

- Comments or explanations cannot be added directly to the picture as text entries
- Images can be difficult to correlate with information contained in other field documentation
- Lack of information about where precisely a particular photo was taken
- Timestamps, if present, may be inaccurate and difficult to correlate
- Transferring images into the project file can be difficult and time-consuming
- Retrieving images later is difficult due to a lack of search capabilities and because photos often have default file names that are obscure and not very meaningful, making it necessary to manually rename them in order to locate the desired image

Virtually all of these issues can be addressed by a mobile tablet device with image capture capability. Large images, as well as video, can be compressed if necessary to make the files easier to manage. A suitable application could be provided that would allow inspectors to provide comments or draw and highlight directly on the photo. The image file can be associated directly with other documentation being generated on the device, making it easier to locate. Location tags and timestamps would be provided automatically, and the tablet could compress and upload the image directly to the project file in a single step.

Once uploaded, these photos could be directly recorded and integrated into daily project documentation. The photos would be immediately available for supervisors or other DOT personnel to review. This makes it a quick and easy process to call in a second set of eyes to take a look at a current situation on a project when questions or concerns arise. In addition, the integration of the photos removes the need for additional data entry and the possibility of redundant or inconsistent information.

Although most participants focused primarily on photo capabilities, for most of these points the same logic applies to video capture as well. Photo and video capability was received by interview participants with a high level of enthusiasm, supported by its average utility score of 4.88 out of 5.

Email Correspondence

Relevant email correspondence can be tagged and saved along with project info

A lot of project communication happens via email, and Project Engineers in particular manage a vast amount of project-related information using email. Much of the correspondence between DOT personnel and contractors is documented using email as well.

Since email is by definition electronic, it already provides a familiar form of reliable documentation that is straightforward to maintain and retrieve. However, since email is normally treated as a separate software program, these records are not integrated into electronic project files without additional steps being involved.

If a secure, web-accessible solution were provided for project inspection work, email capability would be part of the essential basic feature set of the device. In this context, capability could be added to tag, upload, and save relevant emails directly to the project file. This would simplify tracking of project-related emails and make it easy to incorporate these communications into the rest of the project documentation. This capability was extremely well received, especially by personnel who spend more of their time in the office (Project Engineers and management), and earned a utility score of 4.88 out of 5.

QR Codes

QR codes for materials acceptance or prefab components

Interview participants identified a number of different challenges in the materials acceptance process and proper documentation of materials. Prefabricated materials are produced away from the project site and may be initially inspected at the time of fabrication. However, when they are delivered to the project site these materials need to be accepted by the project inspector. The acceptance needs to be documented, including the time of arrival, location, and information about the item or material involved.

Properly verifying, documenting, and accepting these items in the field can be a challenge for project inspectors on the job site. An approach that would capitalize on the capabilities of mobile technology devices would be to handle both verification and documentation with the assistance of QR codes. These are 2-dimensional bar codes that can be scanned with the digital camera of a mobile device such as a tablet and direct it to a predetermined resource. In the context of DOT construction materials, this resource could be a project database or Qualified Products List.

Figure 4. Sample QR code.

In a project inspection scenario, the QR code on an item of material would directly tie to the appropriate record for that material, allowing field inspectors to simply point their built-in camera at the QR code and click to access the complete documentation. The tablet would then automatically associate the documentation with the inspector's records, including the component's delivery time, delivery location, and status, as part of the electronic project file. The description of this feature to interview participants elicited an extremely positive overall response, earning a utility score of 4.88 out of 5.

Notifications and Updates

Updates in real time, where items can be flagged immediately and notifications sent to directly those that need it

Project inspectors are the eyes and ears of the DOT in the field. Their observations and the information they collect need to be directed to appropriate parts of the organization so that other personnel can evaluate the information, take action, and make decisions. Consequently, the capability for inspectors to share their observations with other DOT personnel is critical to maximizing the value of that information.

Mobile technology features can facilitate this sharing with integrated notification capabilities. For example, a project inspector could have the ability to flag a particular item or entry in a daily report, such as a specific photograph, and automatically send a notification to one or more individuals via text message or email. This would allow the inspector to quickly get someone's attention on a particular issue and provide supervisors with direct access to the relevant information in real-time. The description of this feature, which could be implemented using a tablet-based application from the field, elicited a utility score of 4.75 out of 5 from interview participants.

Weather Information

Automatically import weather data based on location (GPS or point on map)

Weather is a vital factor that affects many types of project activities. Decisions about which activities to perform, or when and where to begin work, are sometimes dependent on weather forecasts. Weather conditions also need to be documented as part of project inspection, typically multiple times a day because of the potential for weather changes to affect construction work.

A location-aware tablet device, for example with GPS functionality, could use an internet connection to automatically import weather data for that location. Even without location awareness, a tablet could import appropriate information based on the inspector selecting a point on a map. This capability would enable a push-button mechanism by which weather information could be retrieved and automatically added to project documentation. Interview participants gave this feature a utility score of 4.5 out of 5.

Calculations

Perform calculations automatically in the field for Field Note Records, Inspector Daily Reports, and Daily Work Records

Currently, inspectors spend a significant amount of time in the field performing manual calculations for such things as quantity measurements. A tablet device would have the capability to perform these calculations automatically based on data entered by the inspector.

A generic calculation tool would be expected on any such device and could be used as is, since there is wide variation as to what specific calculations need to be made in the field. However, for particularly common problems or highly complex calculations, there would be an additional benefit to integrating calculation tools directly into the documentation. When the circumstances call for a specific calculation, the device could prompt the inspector with appropriate data entry fields, display the results of the calculation for the inspector to verify, and incorporate it directly into the record. The description of this feature elicited a utility score of 4.25 out of 5 from interview participants.

Electronic Signatures

eSignatures for inspection or quantity reports

Certain issues related to project inspection may require documentation that specific parties were notified or acknowledged the information. For example, when working with contractors in the field, the project inspector must notify the contractor representative of material quantity calculations that will be submitted as part of a Field Note Record. As in this situation, notification is particularly critical for matters that impact contractor pay.

As an illustration of existing practices, WSDOT currently hands the contractor representative a physical piece of paper for signature and provides the contractor with a carbon copy. Using a tablet device with a touchscreen, the project inspector could show the contractor representative the values to be submitted directly on the device. The form could provide a blank area for an electronic signature, which the inspector would ask the representative to provide via the touchscreen. This e-signature would then be saved as part of the form and incorporated into the project file.

Figure 5. Electronic signature input via touchscreen.

Interview participants also mentioned scenarios in which contractor representatives are notified of information verbally, or give verbal agreement to a particular decision. While a verbal communication may be considered sufficient for some purposes, if the communication needs to be documented, an e-signature could be called up at any time and provide an additional element of documentation. The description of this feature elicited a utility score of 3 out of 5 from interview participants.

Summary

Overall, most of the features suggested received high utility ratings from the participants. Many of them correspond to particular challenges identified as part of the interviews. The ability to integrate these capabilities into the documentation process seems to support a consensus that the features could provide value both to project inspection personnel in the field and engineering personnel in project and central offices. Since the information would be integrated with project files in real-time and accessible via a secured web interface, it could be available to anyone in the organization who might benefit, including management. The projected benefits to the DOT are discussed in the next section.

Projected Outcomes

There are three main projected outcomes anticipated by streamlining project inspection using the capabilities described in the previous sections. Projected outcomes are intended to be measurable elements, components of which will be evaluated in Phase II of this research project. They include the following:

Figure 6. Projected outcomes from streamlining project inspection.

Time and Cost Incentives

Significant tangible productivity enhancements can be achieved through the use of mobile tools for project inspection. This is evident from the time expenditures identified during the interview phase of this research, which involve a considerable portion of tasks that could be accelerated by a combination of technology and mobility features. Currently, project inspectors must either handle this work using existing technology that is not mobile in nature, or they must attempt to perform the tasks directly in the field (i.e., while mobile) without technology available that might assist them.

Overall, the interviews indicate that 62.5% of inspector time is spent entering information into the computer, referencing information in the field, and performing calculations in the field. These are all activities that properly designed mobile tools can accelerate. In addition, some of these activities are currently separated from each other in terms of the inspector's workflow, such as by requiring different tools or being performed in different locations. Additional efficiencies would be possible if activities can be consolidated to take place with the assistance of a single device, such as a mobile tablet.

Based on the analysis of the responses from the interviews conducted under this phase of research, it is hypothesized that appropriate mobile tools could reduce the time devoted to these responsibilities by one-half, meaning that the projected outcome involves a savings of approximately 31% of inspectors' time and effort. To measure this outcome, the research team would track time spent for each of these activities: entering data in the computer, searching plans and specifications for information, and performing calculations using the mobile tool. The activities would be measured and compared against existing time expenditures reported in the interviews to evaluate how well mobile technology achieved the projected outcome.

Projected Outcome	Significant Time and Cost Incentives
Anticipated Value	**31% Productivity Gain**
Measurable Elements	Time spent entering data
	Time spent searching in plans and specifications
	Time for performing calculations

Table 15: Projected outcome for assessing time and cost savings

Assuming a time savings of 31%, the added productivity from mobile technology would translate to roughly 1.5 days a week per inspector. At regular pay rates, this equates to a time efficiency gain with a value of $15,500 per inspector, per year. This value is based on a standard 8-hour workday and does not attempt to factor in higher overtime rates, even though the interviews indicated that needs for overtime were common.

Applied to the agencies under study, the value of the estimated productivity gains would be substantial. WSDOT has 397 project inspectors, which would mean an annual value of $6,150,000 in increased productivity. For TxDOT, which has 1,092 project inspectors, the productivity increase would amount to a value of $16,900,000. These numbers do not factor in overtime rates, possible savings on liabilities and claims, or collateral productivity benefits for Project Engineers and management personnel.

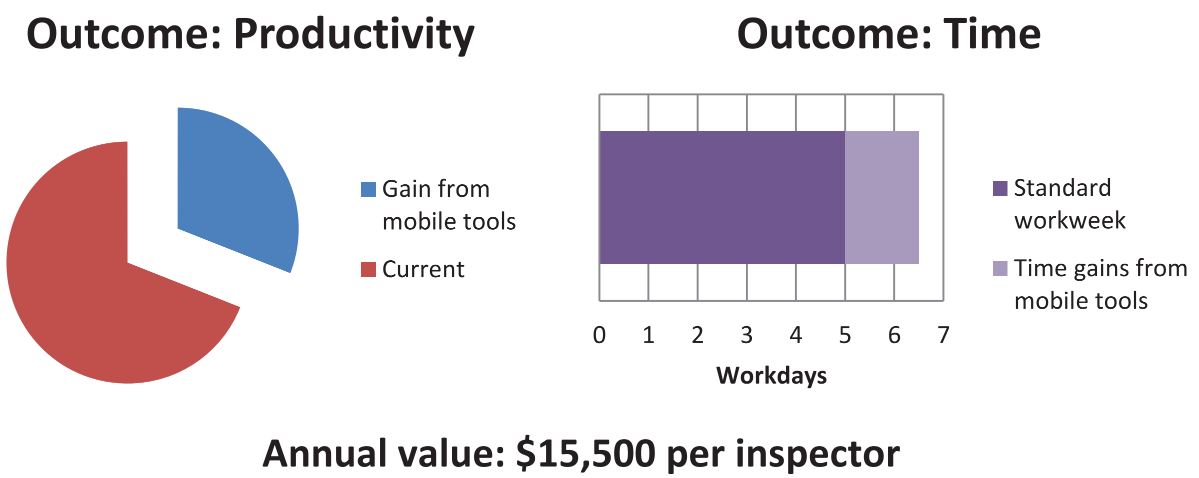

Figure 8. Projected value of increased productivity and time efficiency.

Viewed another way, increasing inspector productivity would effectively increase the capacity of DOT workforces without requiring additional staff. In theory, mobile tools would allow WSDOT's 397 inspectors to perform like a workforce of 520 project inspectors. In the case of TxDOT, this projected boost in productivity boost would go a long way toward covering existing staffing shortfalls. TxDOT provided an FTE spreadsheet tool indicating that in order to cover 843 projects in 2013, the agency would need to have 1,445 inspectors. The anticipated gain from mobile technology would allow the current workforce of 1,092 inspectors to handle work equivalent to 1,430 inspectors, thus filling more than 95% of the gap simply by providing existing personnel with better tools.

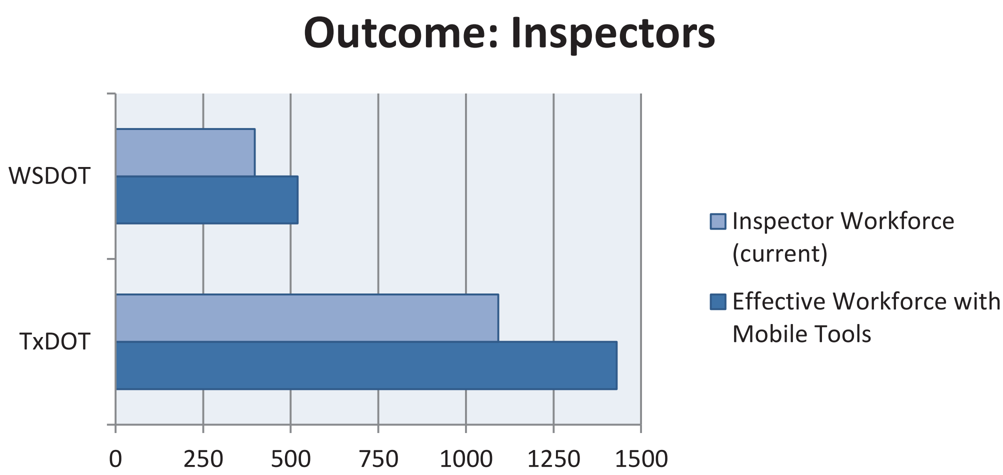

Figure 9. Projected increase in effective workforce.

Data Quality Incentives

Another area where significant value can be realized involves looking at the quality of the data being collected in the field as part of project inspection. Multiple scenarios related in interviews indicated that having information from inspections led to saving large sums on claims or change orders. Being able to properly collect this information is an important factor in realizing its value. The reverse is also true, in the sense that when particular data points are unavailable or were missed during inspections, this can lead to significant costs to the agency because information was not accounted for.

Using mobile tools to collect inspection information has a number of potential benefits with respect to data quality. These include the ability to dynamically and automatically check for errors in data entry, improved consistency from collecting data primarily through a single device, and the potential to have tools that reliably and automatically supply certain data directly into the system. Some representative illustrations of each of these examples:

- Checking for errors – A mobile device could be programmed with established data entry parameters for a particular data point, such as pavement density, and prompt the inspector if a value is entered that falls outside these parameters.
- Consistency of data – By consolidating data collection activity to a mobile tool, particularly one that could communicate directly with agency databases from the field, inspectors would be able to reduce errors from transcription or duplication of data.
- Automatically populated data – Mobile tools would allow inspectors to take advantage of technology to automatically include important data such as weather and location.

The outcome, in terms of the impact on data entry errors, is projected to be a significant reduction. In addition, part of the benefit of mobile tools is not simply eliminating instances of incorrect data, but catching those instances at a point in time where the correct data is still available to the inspector. This would prevent scenarios in which someone might look at the information and know that some data must have been incorrectly recorded, but not have the ability to determine the correct information because it can no longer be collected.

By making collection of data easier and more expedient, mobile tools will also allow inspectors to generate more complete and consistent data. This leads to a hypothesized projected outcome in which the overall data collected is targeted at 50% more complete, as well as 50% more consistent. Both of these outcomes lead to the increased collection of high-integrity data. In order to validate these projected outcomes, the volume and accuracy of data collected using mobile technology could be measured and rated, then compared to a representative sample of data from existing inspection methods.

Projected Outcome	Significant Data Quality Incentives
Anticipated Value	**Data 50% more complete, 50% more consistent**
Measurable Elements	Number of data entry errors
	Total volume of data created
	Ratio of data entry errors to total data

Table 16: Projected outcome for quality of inspection data

Data Availability Benefits

Making it easy for inspectors to gather complete, high-integrity data is only the first step in unlocking its value. The next step involves making that information available, potentially in real-time, throughout the organization. This means that multiple people can have access[4] to the information, provide input on field observations, and make decisions based on the information collected.

For example, first-line managers such as chief inspectors would be able to easily review their inspectors' daily reports and provide any input necessary. The project inspector would not necessarily need to return to the office at the end of the day to submit a report, and the chief inspector could conduct the review either at the office or while on a project site, regardless of whether this was the same site as the project inspector. When the information can be saved directly to the project file via a mobile tool, a second set of eyes can quickly provide input from any location.

Access to real-time inspection information would also increase the capacity of Project Engineers to handle projects. By making the information available in real-time it has the effect of putting Project Engineers virtually in the field, even though most of their work might be done from a desk in the office. As an additional time and cost savings, transportation time for personnel to travel from the project office to the field site can be reduced because the information is made available directly. In addition, the data can be shared between different departments within the DOT if desired.

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[4] Only individuals with proper permissions would be allowed access to project information, including through mobile tools.

The hypothesized projected outcome of improved data availability can be tracked using several different measurable characteristics. With all data incorporated directly into the project file, it is possible to compare the number of times information is viewed, including views broken down by particular roles, such as project inspectors, chief inspectors, and project engineers. The timing of when information is viewed could also be tracked to evaluate the benefits of real-time availability, whether reviews are taking place the same day or the next day and how activity may be accelerating. In addition, the number of notifications sent through the system, along with the timing of responses that occur, would indicate the availability of information to different project staff.

Projected Outcome	Significant Data Availability Benefits
Anticipated Value	**Data dissemination 50% faster, 50% more widely**
Measurable Elements	Timing of information views relative to collection date
	Total number of times information is viewed
	Number of distinct individual viewers of information

Table 17: Projected outcome for data availability

Summary

Implementing mobile technology to assist project personnel is anticipated to have significant benefits for transportation agencies. The projected outcomes include time and cost savings through increased inspector productivity, improvements in quality through production of more complete and consistent inspection data, and better decision-making through the availability of data in real-time.

Conclusions and Next Steps

Based on the information gathered and the findings from Phase I, the pilot program identified for Phase II will provide quantitative measurements of the projected outcomes to be realized from mobile technology and chart the direction toward a broader implementation.

The Phase II pilot activity is supported by the following findings from the Phase I research:

Finding 1: The data gathered by project inspectors in the field is highly valuable.
Finding 2: There are identified challenges gathering that data in the field.
Finding 3: There are challenges sharing that data within the organization.
Finding 4: Opportunities exist to improve how resources are accessed in the field, such as plans, specifications, and construction manuals.
Finding 5: Significant time is spent on activities in the field that mobile technology can assist.
Finding 6: There is no significant resistance by agency personnel to using mobile technology in the field.
Finding 7: Both field and office personnel would benefit from being able to share information collected in the field in real-time.
Finding 8: There is an opportunity to improve the quality of the data currently being collected in the field.
Finding 9: Project Engineers would benefit from the ability to streamline how project correspondence information is stored and retrieved.

Finding 10: There is significant time spent in areas that mobile technology can be applied and the projected outcomes are measurable.

To improve the project inspection business process, the benefits form mobile technology warrant further investment in the development of appropriate tools. The focus of Phase II activities will be to create a pilot solution with a set of capabilities to support project inspection data collection in the field. Defined measurable elements will be established for each of the pilot activities and tested in the field on live projects. The results from these tests will be used to assess the measured outcomes and compare them to the projected outcomes from Phase I. This pilot data can then serve as the basis for a recommendation as to whether agency-wide deployment of the solution should be considered.

Phase II Pilot Approach

The pilot program in Phase II would be implemented via live field testing for a 1-2 month period. During the development of the tools for the pilot, the research team will work with the DOTs to define the measurable elements to be evaluated as part of the testing. These measurements will be selected in order to allow points of comparison with the corresponding current project inspection practices.

Phase II Capabilities

The Phase II pilot solution should include capabilities that support work both in the field and from the office. The primary emphasis will be on providing tools for project inspectors in the field including:

- Consistent, seamless image capture, including the ability to write notes on the image, compress, and upload easily
- Location and time stamping for photos and data entered in the field
- QR code generation and detection for materials acceptance or prefabricated components
- Real-time updates for flagging items and sending notifications
- Automatic import of weather data based on location
- The capacity to store, access, and search electronic project documents (plans, specifications, manuals, etc.)
- The ability to generate daily reports (IDR/DWR documents) directly from the solution

The pilot solution also needs to support project personnel who are in the office, such as Project Engineers, by providing the following capabilities:

- The ability to tag and save relevant email correspondence directly with the project info in the solution's project file
- Secured web access to all recorded project information

It is expected that the Phase II field testing will leverage the participants in Phase I interviews as a core group to participate in the pilot. The pilot solution will include the ability to collect feedback, and additional impressions and suggestions regarding the tools can be gathered in brief follow-up interviews. Upon conclusion of the pilot program, a summary report will be created to document and interpret the results of the Phase II pilot. The research team will provide recommendations for broader implementation of mobile tools for project inspection based on the conclusions drawn from the pilot program.

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