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The Value of Cloud Computing Technology in Public Transportation Construction

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Abstract

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The analysis of large datasets to create value using cloud computing technology has helped many industries improve decision-making processes and better predict risk. The construction of transportation infrastructure systems managed by Departments of Transportation (DOT) produce significant amounts of project data that are stored in various locations by individuals working in multiple agency offices at every phase of the project's lifecycle. Currently, DOTs do not have effective tools or processes to gather and analyze this fragmented data. Project records are generally stored in either physical repositories (e.g., actual paper files and file cabinets) or digital repositories (unsearchable file types and folders on multiple computers and servers) that are not able to be accessed by computers and/or whose contents cannot be searched and processed making it difficult, if not impossible, to create value from this vast amount of data. The exchange of project data throughout a DOT's entire organization can create opportunities for new decision-making applications to better manage the development and operation of transportation infrastructure.

To date, there has not been any significant literature studying the adoption of cloud computing technologies by DOTs. In general, DOTs have implemented market ready technologies and processes (e.g., mobile devices and electronic signatures) in an ad-hoc manner, limiting the results of these initiatives to a small group of users. The principal objective of this research is to examine the value of

cloud computing technology in highway construction inspection. Data and observations are collected from the implementation of a cloud computing technology specifically developed for DOT project inspection, named HeadLight, to the Washington State DOT, Minnesota DOT, Texas DOT, Rhode Island DOT, and Louisiana Department of Transportation and Development (WSDOT, MnDOT, TxDOT, RIDOT, LADOTD respectively). The dissertation examines the following:

1. Productivity and data quality improvements associated with the use of HeadLight compared to traditional inspection practices

2. How the implementation method and organizational change management activities affect acceptance and adoption of new technologies

3. How HeadLight and the data collected within can be used beyond its intended project inspection purpose to create additional value throughout the organization

Contributions of this work include (1) empirical measures of productivity and data quality improvements associated with the use of cloud computing technology over traditional inspection methods that can help transportation agencies understand and articulate the benefits of investing in such technology solutions, (2) examination of a DOT technology implementation case study identifying key organizational change management factors that promote the likelihood of technology adoption for transportation agencies, and (3) potential applications of construction inspection data for project management, asset management, and environmental compliance offices. The outcomes and guidance provided in this dissertation informs transportation agencies the value of cloud computing technology and the importance of managing the implementation process of such technology.

Table of Contents

ii

List of Tables

List of Figures

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1.0 Introduction

The analysis of large data sets to create value, termed big data analytics (Fosso Wamba et al., 2015; Janssen et al., 2016), have allowed many industries to improve decision-making processes and better predict risk (Cai and Zhu, 2015). Cloud computing technology which allows users to collect, disseminate, and analyze data by providing application, storage, and processing services connected through a real-time network (Chong et al., 2014), has been adopted by these industries to perform big data analytics. For example, the controlled exchange of medical records, claims and cost data, and research and development data has enabled the healthcare industry to reduce healthcare spending, improve patient diagnosis time, discover adverse drug effects, and predict increases in flu-related emergency room visits (Raghupathi and Raghupathi, 2014). Cloud computing has helped retail businesses, such as Amazon, by allowing consumers to search product listings from a large number of vendors to improve price transparency (Muhtaroglu et al., 2013). In the building construction sector, building information modeling (BIM) systems have connected the architecture, engineering, and construction disciplines with a virtual model of a building project which can be used throughout the project's lifecycle (Azhar, 2011). BIM has been used to reduce design conflicts, better predict building performance and operation, and reduce costs and delays through improved collaboration between design and construction teams (Azhar, 2011; Ahn et al. 2016). The transportation sector has used intelligent transportation systems (ITS) and social transportation data to improve traffic operations. Data collected from ITS sensors, such as in-road loop detectors and video image processors, has helped reduce congestion, predict collisions, and improved travel time estimations (Shi and Abdel-Aty, 2015). Social transportation data has been used by Waze, a community-based traffic and navigation application owned by Google. The users of Waze share traffic and other route information which provides its community with real-time GPS-navigation services and traffic conditions (Muhtaroglu et al., 2013). These examples demonstrate the leverage of collecting and analyzing diverse datasets obtained through various processes to create value.

Similar to the industries described above, the construction of transportation infrastructure systems managed by Departments of Transportation (DOT) produce significant amounts of project data that are stored in various locations by individuals working in multiple agency offices at every phase of the project's lifecycle. For example, field inspectors generate inspection records to document the site conditions, progress of work, and decisions made onsite. Material engineers produce material acceptance records to ensure the materials used on project meets the quality standards set forth in the

specifications. Environmental engineers produce sediment and erosion control records to ensure the construction of the infrastructure complies to environmental standards.

Currently, DOTs do not have effective tools or processes to gather and analyze this fragmented data. These project records, generally in the form of plans and reports, are stored in either physical repositories (e.g., actual paper files and file cabinets) or digital repositories (unsearchable file types and folders on multiple computers) that are not able to be accessed by computers and/or whose contents cannot be searched and processed making it difficult, if not impossible, to create value from this vast amount of data. The exchange of project data throughout a DOT's entire organization can create opportunities for new decision-making applications to better manage the development and operation of transportation infrastructure.

1.1 Scope

To date, there has not been any significant literature studying the adoption of cloud computing technologies by DOTs. In general, DOTs have implemented market ready technologies and processes (e.g., mobile devices and electronic signatures) in an ad-hoc manner, limiting the results of these initiatives to a small group of users (Shah et al. 2017). This dissertation contributes to the body of knowledge by examining the implementation of a cloud computing technology by multiple DOT construction offices. The principal research question for this dissertation is *what is the value of cloud computing technology in highway construction inspection?* To answer this broad research question, this dissertation conducts three individual studies that focus on the following questions:

1. How does cloud computing technology affect personnel productivity and inspection data quality when used to mimic traditional inspection practices?
2. How does the implementation method of the technology affect its acceptance and adoption?
3. How can cloud computing technology and the data collected within be used beyond its intended project inspection purpose to create additional value throughout the organization?

These research questions are chosen as a literature review establishes the following hypotheses:

- Modern technology can alleviate some of the time-consuming administrative tasks involved in traditional project inspection processes
- Organizational change management of modern technology implementation efforts is as important, if not more, as the technology itself

- The use of cloud computing technology has created new applications and values for many industries (e.g., retail, health care, building construction)

This dissertation uses the data and observations collected from the implementation of a cloud computing technology specifically developed for DOT project inspection, named HeadLight, to the Washington State DOT, Minnesota DOT, Texas DOT, Rhode Island DOT, and Louisiana Department of Transportation and Development (WSDOT, MnDOT, TxDOT, RIDOT, LADOTD respectively) to answer the three questions presented above. The implementation of HeadLight for these DOTs are chosen as basis of this dissertation for the following reasons:

- My involvement in the DOT implementations of HeadLight provides the experience and context needed for this dissertation
- Data and personnel participation from these implementation activities were made available for this dissertation

It is worth noting the limitations of the studies included in this dissertation. First, this dissertation is based off the use of the HeadLight system, developed for specific DOT project inspection purposes. This dissertation reflects the use of HeadLight by DOTs and readers should be cautious about generalizing the results and findings to the private construction industry and other stakeholders within the construction engineering community. Secondly, the studies included in this dissertation are based on cases that were available at the time of this research and were not randomly selected. The number of participants, agency culture, length of use, intended use of the technology, technology integration method, and other factors can affect the outcome of the metrics used in this dissertation.

The following section provides the background of the HeadLight system how the author's involvement in the implementation programs contributed to this dissertation.

1.2 Background

In 2013, the first phase of a multi-phase research initiative, led by WSDOT and conducted in cooperation with TxDOT and the Federal Highway Administration (FHWA), examined the feasibility of using mobile and cloud computing technologies for project inspection (Snow et al. 2013). This study found project managers heavily relied on timely inspection data to make decisions and field inspectors needed more efficient tools and processes to collect and report field data. These findings determined that DOT project inspection was an ideal market entry point for mobile and cloud computing technologies.

The second phase of the research initiative involved the development and piloting of a technology solution named HeadLight. A Seattle based company, Pavia Systems, Inc., worked with WSDOT to develop HeadLight, a project inspection database management system that incorporates a mobile and web-based application to collect and view field data and a private network operations center where the data is securely stored and managed through a cloud infrastructure. In 2014, HeadLight was deployed to WSDOT, MnDOT, and TxDOT on a trial-basis. The pilot program consisted of a 3-month long trial period which examined the technology's impact on personnel productivity and data quality. These metrics were hypothesized in the first phase of the research to having the most impact on the project inspection processes. I was employed by Pavia Systems to help implement HeadLight and author the DOT research report for the second phase of the research initiative. I was specifically involved with training personnel on using the technology, being on site to provide technical assistance, and collect data and other needed materials to author the DOT report. With Pavia Systems and the DOTs' permission and cooperation, the data and observations collected from this pilot study is used in Chapter 2 of this dissertation addresses the question *how does cloud computing technology affect personnel productivity and inspection data quality when used to mimic traditional inspection practices?*

The positive outcomes and reception of the pilot program resulted in a larger implementation research program in 2015. This phase of the research initiative only involved WSDOT, where HeadLight was implemented with 18 project engineering offices (PEOs) across the state in a year-long program. I continued to work for Pavia Systems during this implementation, being involved with the initial training, technical support, and conducting a user assessment study 3 months into the deployment period. The objective of this study was to understand, through participant interviews, how HeadLight users interacted with system and to identify issues and obstacles encountered by users to further develop HeadLight to meet the agency's inspection needs. At the end of this larger scale implementation, 14 out of the 18 PEOs decided to discontinue the use of HeadLight. The result of this implementation effort led to the formation of the research topic covered in Chapter 3 of this dissertation. Data and observations collected from the 2015 WSDOT HeadLight implementation research program is used to answer the question *how does the implementation method of the technology affect its acceptance and adoption?*

By 2018, the HeadLight system has been implemented by over 15 DOTs (city, county, and state) and construction, inspection, and engineering (CEI) firms. For over 3 years, these agencies and companies have collected vast amounts of inspection data using HeadLight. This creates an opportunity to apply the big data approach in analyzing large datasets collected from multiple HeadLight users over an extended

duration of time. Chapter 4 of this dissertation uses the inspection data collected from 11 WSDOT, RIDOT, and LADOTD projects to examine the current and potential uses of HeadLight. These three DOTs were selected as each DOT deployed HeadLight in different capacities. WSDOT fully deployed HeadLight on four of their projects for over 3 years, RIDOT has been using HeadLight on a trial basis for approximately 4 months, and LADOTD has directly integrated HeadLight with their legacy construction management system and has used this integrated system for about 10 months. The HeadLight dataset collected by these DOTs is used to answer the question *how can cloud computing technology and the data collected within be used beyond its intended project inspection purpose to create additional value throughout the organization?*

1.3 Contributions

As the use of cloud computing technology is relatively new to the civil infrastructure industry, the contribution of this dissertation is to describe the value of such technology in highway construction inspection. This dissertation can also be used as a guide in adopting cloud computing technology specifically for transportation agencies. The specific contributions of the three studies int his dissertation include:

- **Empirical measures of productivity and data quality improvements resulting from the adoption of a cloud-based data management system.** This study assesses the impact of cloud-based project data management system, used for project inspection, implemented to large participant groups (31 construction projects across 3 state DOTs) over a 3-month time span. Changes to productivity, amount of data collected, and data quality defined as completeness, variety, timeliness, and availability are empirically measured in this study. Previous studies that collected empirical data on time savings from using modern technology, such as mobile technology, typically use small participant groups over a short period of time, limiting their findings to short-term small-scale deployments. Majority of these studies are performed for the building construction sector and limited studies are available for the transportation sector. Furthermore, studies on the effect of cloud-based mobile technology on data quantity and quality are often not examined.
- **Identification of key factors specific to DOTs that influence the acceptance of new technologies and processes.** This study provides best practices in technology and process adoption focused on DOTs. The key technology and process acceptance factors are determined from one specific change that is made throughout multiple regions of a state DOT. Existing

studies generally create change management strategies based on data from various change initiatives (i.e. software, business strategy, management operations) collected throughout the architectural, engineering, and construction (AEC) community. There are limited studies that create or validate existing change managing strategies for technology adoption aimed for DOTs.

- **Applications of project inspection data beyond the administrative, legal, and record-keeping purposes.** This study demonstrates potential new applications of the inspection data collected in HeadLight for asset management and environmental compliance operations. These operations are generally managed by divisions outside of the construction division, and do not have direct means of accessing the large dataset generated from project inspection personnel. Much like the industries that have improved their operations and decision-making process through the use of big data analytics, this research presents examples on how DOT asset management and environmental management divisions can benefit from project inspection data using HeadLight's cloud computing capabilities.

1.4 Dissertation Format

This dissertation is composed of three independent studies formatted as journal articles. Chapters 2, 3, and 4 are independent studies, each study addressing research questions 1, 2, and 3 respectively. The study described in chapter 2 has been published in the Journal of Automation in Construction in August 2018. As of October 2018, Chapter 3 has been accepted for publication in the upcoming Transportation Research Record journal. Chapter 4 is intended to be submitted in a journal article after the publication of this dissertation. The following list provides the content included in each chapter of this dissertation.

- **Chapter 1.** Presents the central theme and contributions of this dissertation.
- **Chapters 2.** Describes the small-scale deployment of HeadLight to WSDOT, MnDOT, and TxDOT and measures personnel productivity and inspection data quality improvements compared to the traditional inspection process.
- **Chapter 3.** Describes the large-scale WSDOT HeadLight implementation with 18 PEOs, identifies key organizational change management factors that influence the adoption of new technologies and processes, and provides best practices towards successful technology adoption.
- **Chapter 4.** Investigates potential new applications of the inspection data collected using HeadLight by WSDOT, RIDOT, and LADOTD to create value for the construction, environmental, and asset management DOT offices.
- **Chapter 5.** Presents the overall conclusions of this entire dissertation.

- **Chapter 6.** References.

- **Appendix A.** Presents the data collection guide used for the study in Chapter 2.

- **Appendix B.** Presents the interview questions for inspectors that participated in the study described in Chapter 2.

- **Appendix C.** Presents the interview questions for office and management personnel that participated in the study described in Chapter 2.

2.0 Assessing the Impacts of Cloud-Based Mobile Technology on Public Transportation Project Inspection

2.1 Preface

The previous chapter discussed the potential of cloud computing technology to collect and distribute project data and information in a more transparent and efficient manner. This chapter describes the implementation of the HeadLight platform and its impact on the project inspection process. Although HeadLight is developed to manage project datasets produced from many different workforce divisions within the DOT, construction inspection was found to be a convenient market entry point to pilot this new technology and its ensuing data collection and dissemination processes. The HeadLight Mobile Inspection platform was designed to mimic the traditional inspection administrative workflow process to adhere to the standard project record retention policy.

The study described in this chapter has been published by Elsevier in the Automation in Construction journal. The journal article can be found using the following link (DOI):

https://doi.org/10.1016/j.autcon.2018.08.021

2.2 Abstract

Advancements in mobile technology capabilities and affordability allow many Departments of Transportation (DOT) the opportunity to use these technologies to improve the time-consuming nature of collecting, documenting, and distributing project inspection information. A mobile technology system for project inspection, called HeadLight, is piloted with the Washington, Minnesota, and Texas Departments of Transportation on 31projects over a 3-month time span. Field measurements and interviews are used to quantify improvements offered by mobile technology over current practice. This empirical data is evaluated using standard software and process change evaluation metrics: time savings, data volume, data variety, data completeness, data timeliness, and data availability. Results indicate that project inspectors using the mobile technology system experienced productivity gains on the order of 25%, collected and shared twice 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 allows the inspection workforce to work more efficiently. Further study into improved data quality and availability may identify more impacts within the construction inspection process and to a DOT's decision making processes.

2.3 Introduction

Project inspectors working for Departments of Transportation (DOT) are responsible for collecting vast amounts of data and information in the field. Acquiring timely and accurate inspection information assists in tracking project control elements such as cost, schedule, and materials that aid project delivery. However, public spending on transportation infrastructure projects has been steadily declining and budget limitations have generally led DOTs to reduce their workforce levels (TRB 2003; Warne 2003; Jagars-Cohen et al. 2009; Mostafavi et al. 2013; ASCE 2017) making it difficult for a reduced inspection workforce to collect a growing amount of information each year.

On average, project inspectors spend nearly half of their shift collecting inspection information in the field (McCullouch 1991; Saidi et al. 2002; Asbahan and DiGirolamo 2012; Snow et al. 2013; Valdes and Perdomo 2013). The remaining portion of their shift is typically spent performing administrative tasks such as entering information into a computer and looking up information in the project reference documents such as plans and specifications (McCullouch and Gunn 1993; Snow et al. 2013; Valdes and Perdomo 2013). Studies (McCullouch 1991; McCullouch and Gunn 1993; Saidi et al. 2002; Asbahan and DiGirolamo 2012; Snow et al. 2013; Valdes and Perdomo 2013) indicate that project inspectors are not able to inspect elements of the project for half of their shift, potentially failing to collect crucial inspection information that may have an impact on the progress, quality, and cost of the project.

Mobile technology, defined as the hardware and software that can be used in concert to allow integrated real-time entry and access of project-related information, and data communication capabilities, continue to improve and have become affordable, allowing many DOTs the opportunity to use these technologies to improve the time-consuming nature of collecting, documenting, and distributing project inspection information. While mobile technology has been around since the early 1990s, device connectivity has improved allowing personnel to reliably download and upload information directly onsite. However, industry may be hesitant to adopt new technology due to the lack of empirical data on user performance benefits needed to justify the investment (Bowden et al. 2005; Kim and Kim 2011). Majority of research reporting the user benefits of this technology have based their findings on qualitative data, such as participant interviews and surveys, and have not examined how the technology impacts the quality of data collected on site in detail. Furthermore, finding and customizing mobile technology to meet a specific DOT's business, administrative, and inspection process can be challenging.

This research contributes to the existing body of knowledge by collecting empirical data used to measure changes in productivity and data quality associated with the implementation of a mobile technology system that was developed specifically for DOT project inspection practices. Quantifying the end user benefits and understanding data quality changes resulting from the adoption of mobile technologies can help transportation agencies understand and articulate the benefits of investing in such technology solutions.

2.3.1 Scope

This paper describes the second phase of the multi-stage DOT research effort that investigates the use of a cloud-based mobile project inspection application to improve personnel productivity and the inspection workflow processes. The first phase, conducted in 2013, examined the user requirements for developing the technology which warranted its development and deployment (Snow et al., 2013). This paper focuses on the second phase of this research effort where a cloud-based mobile technology system, called HeadLight, is developed by the Washington State DOT (WSDOT) with a Seattle-based Company Pavia Systems, Inc., and piloted with the WSDOT, Minnesota, and Texas DOTs (WSDOT, MnDOT, and TxDOT respectively) on 31 projects over a 3-month time span. Field measurements and interviews are used to quantify improvements offered by mobile technology over current practice. This empirical data is evaluated using standard software and process change evaluation metrics: time savings, data volume, data variety, data completeness, data timeliness, and data availability (Wand and Wang, 1996; Batini et al., 2009; Snow et al., 2013; Cai and Zhu, 2015; Wamba et al.,2015). These quantified metrics can be used to better describe the likely benefits of mobile technology, evaluate its adoption implications, and include resulting benefits in business process models.

2.3.2 Previous Work

Research on using mobile technology to reduce administrative efforts associated with construction field documentation have been conducted since the 1990s (e.g. McCulloch and Gunn 1993; Liu 2000; Saidi et al. 2002; Bowden et al. 2005; Kimoto et al. 2005; Boddy et al. 2007; Kim and Kim 2011; Valdes and Perdomo 2013; Nguyen et al. 2015). Past studies have generally presented details on the development, functionality, and the application of the mobile system. Literature on the impacts of mobile technology for project inspection have not discussed in detail how the data collected onsite changes with the use of tools such as tablet computers. Few authors have examined the benefits and process changes resulting from the adoption of these technologies and only a small portion of these studies have collected empirical performance data, and even then only over a short period of time with a small group of

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participants. Information on the time savings and productivity improvements of using mobile technology in construction applications have typically been collected through survey responses and similar qualitative data. McCullouch and Gunn (1993) developed and field tested a time keeping application for DFM Travelite pen-based handheld computers on two industrial construction projects. The authors concluded that end user perception of data collection time was similar to that of the paper based method but they saved time from not having to duplicate their timekeeping data in their electronic data management system. Liu (2000) developed and tested an electronic tunnel inspection form identical to the paper form on a handheld PC which automatically uploaded the information to a web server. Comments from ten participants that used the system for one day concluded that the users saved time in filling out inspection reports but the mobile hardware was not rugged enough to endure the rough constriction site environment. Saidi et al. (2002) estimated the time consumption differences between the paper-based method and the handheld computer method for six construction field activities and showed activities can be performed more efficiently by using handheld computers onsite. Bowden et al. (2005) assembled case studies and previous research related to mobile technology use in construction and found that these technologies can potentially help reduce construction time and cost, defects, accidents, waste, and operation and maintenance costs while improving productivity. The study identified major barriers to innovative IT technology adoption in the industry which included the lack of empirical performance and benefit data as well as the mismatch between information technology developed by researchers compared to the actual needs of the end users in the construction industry. Kimoto et al. (2005) conducted interviews with construction managers working on building projects to identify key user requirements that were used to develop a building inspection application. The mobile data collection system developed by the researchers allowed text based field data to be collected on a mobile personal digital assistant (PDA) device and saved to a memory card for further PC analysis at the office. This approach eliminated the duplication of data collected from the field to the PC and reduced the time taken for such administrative work. Rojas et al. (2009) examined the use of paper forms, laptop computers, digital pens, and handheld computers in capturing existing facility as-built information and found handheld computers to be the most time and cost efficient method. Direct measurements of task completion times revealed that handheld computer users were able collect as-built data approximately three times faster than the paper-based method. Zhang et al. (2016) developed and tested a prototype of a tablet computer application that allowed inspection managers to collect observations and generate reports onsite. Post-trial interview responses from four safety managers indicated a perceived increase in efficiency of data collection onsite and easier photo integration into their safety reports.

11

Research on mobile technology specific to use in DOTs have focused on similar impacts, typically discussing process time savings and improved access to project reference documentation. Asbahan and DiGirolamo (2012) provided tablet computers, preloaded with project reference documents, to ten inspectors working on Pennsylvania DOT projects for one month. Participant surveys revealed that inspectors perceived the use of tablet computers helped them save about twenty minutes per day on tasks related to finding content in the project reference documents. The resulting time savings allowed them to spend more time on general field inspection activities. The participants perceived no time savings from filling out paperwork and daily reports. Valdes and Perdomo's (2013) documented the development of a prototype application for tablet computers that creates inspection daily reports for the inspectors working for the Puerto Rico Highway and Transportation Authority. The prototype was field tested to an unspecified amount of inspectors for few weeks but the study did not collect any data that measured performance impacts.

2.3.3 Current State of Inspection Practice

DOTs still rely, at least partly if not wholly, on a paper-based approach in field data collection for project inspection. According to a 2017 AASHTO survey (Shah et al. 2017), 21 out of 26 DOTs surveyed use a mix of manual and electronic system to track inspection and material test results (e.g., data is collected in the field on paper and transferred to the DOT's electronic documentation system later), while another three rely completely on paper methods and do not use electronic documentation systems (Shah et al. 2017). The other two DOTs use electronic systems to track all inspection and material test results. Earlier work by Valdes and Perdomo (2013) corroborate these findings.

2.4 Method

This study evaluates the changes in the business practice and field inspection data resulting from the use of a mobile technology system through empirical field testing conducted with WSDOT, MnDOT, and TxDOT. The business practice and data changes were determined by comparing the traditional inspection process with the mobile technology system process using several evaluation metrics. This section discusses the mobile technology system's software and hardware, the research participants and their roles, the business practice affected by the process change, the evaluation metric, and the information gathering process used for this study.

2.4.1 Software and Hardware of the Mobile Technology System

The research team chose to run the mobile technology system as an application on the Apple iPad Air. Each iPad Air was outfitted with a waterproof protective casing and a hand-strap to carry the device in the field. Android tablets and Microsoft's Surface tablets also met the hardware requirements for the pilot study although the scope of the research mandated that only one mobile hardware platform be selected.

The mobile technology system software, named HeadLight, was developed by Pavia Systems, Inc. based on prior user requirements research (Snow et al., 2013). The mobile technology system's three main components are:

- **Mobile client.** The application installed on the mobile hardware (iPad Air). The mobile client (1) provides a set of tools for capturing inspection information, (2) automatically integrates the captured information, such as text and photo observations, directly into inspection reports and allows project inspectors to generate and submit these reports directly from the field, and (3) enables project inspectors to access all project reference documents from the field such as project plans, special provisions, specifications, and other project manuals.
- **Web client.** Application viewable by office personnel on a web browser. The web client allows project engineers, management, and others with permission to access field information and inspection reports collected and generated by the mobile client through a secure web interface.
- **Cloud-based web service.** Manages the data and information amongst 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 the DOT.

Figure 2-1 shows a screenshot of the mobile and web client.

Figure 2-1. Screenshot of the mobile and web client.

2.4.2 Research Participants

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 is assigned to one or more active projects in the field at a time (WSDOT 2012; WSDOT 2014; WSDOT 2015; TxDOT 2004; MnDOT 2014).

- **Project engineers.** In charge of their field office and are accountable for all project-related activity associated with that field office (WSDOT 2012; WSDOT 2014; WSDOT 2015; TxDOT 2004; MnDOT 2014).

- **Management.** Personnel not within a particular field office, but involved when items are escalated or conflict resolution is necessary. Titles can vary; examples include State Construction Engineer, Construction Section Director, and Assistant Regional Administrator (WSDOT 2012; WSDOT 2014; WSDOT 2015; TxDOT 2004; MnDOT 2014).

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 the mobile technology solution, 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:

14

- **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.

The field test included 31 construction projects across all three DOTs (Table 2-1). These projects were primarily selected based on opportunity (i.e., project was being constructed during the field test window). To the extent possible, projects were also selected to include a variety of project types and sizes. Each field and office participant took part in the following pilot program deployment 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 the mobile technology solution 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 use of the mobile technology solution.
- **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; training and technical support were not experimental variables.

Table 2-1. DOT Projects Involved in the Field Test

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

2.4.3 Business Practice Addressed

The inspection business practice 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 (TxDOT 2013). 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. Field data collected by inspectors include documentation of safety, accidents, traffic control, materials, construction practices, equipment, personnel, environment, weather, field issues etc. This data is typically recorded in the inspector's notebook or other paper-based approach and can be supplemented with photos and videos to better portray events (Snow et al., 2013). 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 to 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. Field data recorded in the inspector's notebook is transcribed or reentered into field reports which are stored in the agency's electronic documentation system. If photos, videos, or any other supplemental sources of information have been documented, the field reports mention their availability but do not directly include them. For the States of Washington and Texas project inspectors are required to submit daily reports of activities in the field (WSDOT 2012; WSDOT 2014; WSDOT 2015; TxDOT 2004). 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) (MnDOT 2014). For all three DOTs, these inspection reports perform essentially the same function. They are to be a dispassionate record of what transpired in a day, objectively documenting project related activities. Inspection reports are permanent sources of evidence that document field conditions, basis for acceptance of completed work, contractor performance, and the DOT's project management performance. The specificity and accuracy of the contents in the report are an important source of information used to evaluate or refute contract claims.

17

The mobile technology system was designed to address several inefficiencies observed in the inspector's documentation practice. First, the mobile client was developed to allow inspectors to collect a set of observations commonly captured in the field using a mobile device to alleviate the need to carry multiple devices. Data collected on the mobile client, such as text entries, photos, and videos, is stored and disseminated in one centralized location using the web service. Secondly, the need for inspectors to duplicate field data into field reports was mitigated by developing a report module that automatically integrates specified data into the report. This was hypothesized to decrease the time taken to create field reports and to minimize potential errors from the transcription process (Snow et al., 2013). The field data and reports are synchronized to the web service on a frequent basis to allow access to this information using the web client.

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.

2.4.4 Evaluation Metrics

This study measures the change in productivity and data quality when a mobile technology system is used in place of a traditional inspection information collection and documentation process. The following evaluation metrics were chosen to measure the change in productivity and data quality:

- **Productivity.** Defined as the time spent on data entry, searching through project reference documents, and commuting off site to create and submit inspection reports. These activities were chosen as Snow et al. (2013) identified mobile technology having the largest productivity improvement on these tasks.

- **Data quality.** The completeness, volume, variety, availability, and timeliness of inspection data were used as metrics to measure data quality as these are standard data quality metrics used to evaluates software applications (Wang and Wang 1996; Batini et al. 2009; Cai and Zhu 2015; Womba et al. 2015). This study defines completeness as the captured fraction of all data components associated with an inspection observation needed to objectively portray the actual conditions of the work performed. Mandatory components include date, time, location, and a description of the observed activity. Documenting these components provide a degree of specificity to observations and classifies information using

temporal and geographical parameters, helpful in recalling activities when evaluating construction disputes and claims. Data volume is the overall quantity of observations regardless of form, and data variety describes the number of observation types (e.g., text, photo, video). Including non-textual observations, such as photos and videos, can be more descriptive than text alone. Data availability is defined as the accessibility of project inspection information to project engineers and management and timeliness describes the speed at which data become available to others. Availability and timeliness were chosen as metrics because there are functions beyond project inspection, such as processing payments and managing construction schedules, that rely on timely access to inspection data. Furthermore, project engineers and management need timely access to inspection data to be aware of site conditions, ongoing construction activities, and issues that need to be managed.

2.4.5 Data Collection

The following three general data collection methods were used:

- **Direct measurements.** Researchers used quantifiable measuring techniques to evaluate the metrics for the projected outcomes. A total of 28, 34, and 40 measurements were made for WSDOT, MnDOT, and TxDOT respectively. The method used for direct measurements depend on the key metric and is further explained in the subsequent sections. 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. A total of 76 WSDOT IDRs, 28 MnDOT WCRs, and 60 TxDOT DWRs were reviewed and compared with all reports generated using the mobile technology system during the field testing.

- **Interviews.** Researchers administered structured, one hour face-to-face interviews with the following number of participants after field testing.
  - WSDOT: 6 field users and 2 project engineer/management
  - MnDOT: 9 field users and 4 project engineer/management
  - TxDOT: 9 field users and 5 project engineer/management

Interview questions were developed in advance and the same questions were asked of all participants.

2.4.6 Measurement Approach

The following sections describe the measurement approach taken for each metric.

2.4.6.1 Productivity

The following activities were used to measure the change in productivity:

Time spent creating construction report documents

- **Direct measurements.** Researchers used a stopwatch to measure the time spent creating inspection reports using the traditional and the mobile technology system process. To measure the time spent creating the report using the traditional method, a research assistant started the stopwatch when a blank daily report template appeared on the inspector's laptop. The research assistant measured the time it took for the inspector to type in all mandatory fields and the diary portion of the report. The stopwatch was stopped once the inspector informed the research assistant that they were finished with the report. To measure the time spent creating the daily report using the mobile technology solution, the research assistant started the stopwatch when the inspector opened the document function in the application. The researcher measured the time it took for the inspector to specify the report date, select the observations made on the specified date to include in the report (all observations are selected as the default), and tap on a finish button. The stopwatch was stopped once the finish button was selected.

Time spent searching for content in the project reference documents

- **Direct measurements.** Researchers used a stopwatch to measure the time spent looking for a specific item in the plan drawings or specifications as required in the field. Physical paper versions were used for the traditional process and electronic versions were used for the mobile technology solution process. Searching through paper versions of the plans and specifications was chosen as the baseline traditional process as this method was identified as common practice for all inspectors participating in this study. If an item was searched for in the paper copy of the plans, a different item would be searched for in the electronic version of the plans as the inspector knows the location of the specific item from the first

search effort. The inspectors were allowed to use the search function in the electronic versions of the plans.

Time saved from reduced travel off site to complete or submit documentation

- **Interviews.** Researchers asked participants to estimate any travel time savings stemming from the use of the mobile technology system.

Overall time saved from using the mobile technology system

- **Interviews.** Researchers asked participants to estimate the overall time savings resulting from the use of the mobile technology system.

2.4.6.2 Data Quality

The following activities were used to measure the change in data quality:

Volume of observation entries in daily reports

- **Inspection report analysis.** Researchers counted the amount of observations by type for both the traditional and HeadLight processes. Since the formatting of the daily report differs from one DOT agency to another, guidelines (e.g., Figure 2-2) were created to account for the number of observations in the reports in a consistent manner with how they were captured using HeadLight.

Variety of observations made per inspector per day

- **Inspection report analysis.** 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 (e.g., Figure 2-2) were created to account for the number of observations in the reports in a consistent manner.

Figure 2-2. Example guideline used to assess the amount of observations in a WSDOT daily report.

Completeness of observations

- **Inspection report analysis.** Similar to counting the volume of observations per report, researchers counted the number of observations associated with a specific time and location in traditional daily reports and the reports generated by the mobile technology. An observation was associated with a specific time if it stated the specific time of when the observation was recorded. Similarly, an observation was associated with a specific location if it recorded a specific station and offset, mile post number, or GPS coordinate.

Availability 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 using a five point Likert scale.

Timeliness of daily inspection reports submission

- **Inspection report analysis.** 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. Researchers were given the date of submission for the traditional daily inspection reports from WSDOT. To assess the timeliness of reports submitted using the mobile technology system, researchers logged in the web-client to record the actual report submission date. It should be noted that this study was only able to compare data related to timeliness of report submission from WSDOT due to a limitation in availability of baseline data for both MnDOT and TxDOT.

2.5 Results

This section presents aggregated results that highlight differences in inspector productivity, data quality, and data accessibility between the traditional and mobile technology solution processes.

2.5.1 Productivity

Table 2-2 shows the amount of time saved from the various productivity metrics. The results show that on average, inspectors using the mobile technology system can save 26 minutes per day generating daily inspection reports and 40 minutes per day searching for content in the project reference documents. Inspectors using the mobile technology system saved an average of 40 minutes per day by reducing the need to travel offsite. It should be noted that the travel time savings result is based on the response of three MnDOT and two TxDOT inspectors.

The difference in the average time spent looking for content using the mobile technology system between MnDOT and TxDOT inspectors can be explained by the size of the projects involved in this study. Several TxDOT inspectors worked on large projects spanning more than 6 miles and with contract values greater than $135 million. These projects typically have larger project reference documents, leading inspectors to spend more time searching through them.

Table 2-3 shows the combined total of the time savings measured from three productivity metrics and compares it to the total time savings that was acquired through participant interview responses.

Table 2-2. Time Spent Creating Construction Report Documents and Searching For Content in Project Reference Documents

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

Notes:
a. Average of the three DOT values
b. Traditional value divided by the mobile technology solution 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 Mobile Technology Solution* 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 the Mobile Technology Solution. This correlates to the time spent for both MnDOT and TxDOT using the Mobile Technology Solution so similar outcomes were anticipated in terms of time savings.

Table 2-3. Comparison of Total Time Savings

Agency	Average Time Saved per Inspector per Day (Interview Response)	Average Time Saved per Inspector per Day (Measured Activities)	Productivity Gain Assuming an 8 hr day[a]
WSDOT	1.50 hours	1.50 hours[b]	23%
MnDOT	1.44 hours	1.67 hours	26%
TxDOT	1.67 hours	1.60 hours	25%
All	**1.54 hours**	**1.59 hours**	**25%**

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 for the traditional process times. Therefore, the time estimated by interviewees (column 1) was used as a reasonable substitute.

2.5.2 Data Quality

Table 2-4 shows the amount of observations collected by inspectors using HeadLight, and Figure 2-3 compares the average variety of the observations types included in daily inspection reports. Traditional reports for all DOTs did not provide the exact locations for media such as photos and videos but noted that they were captured. The HeadLight reports displayed photos and provided a web link to videos so they were included in the results. Table 2-5 shows the average amount of data collected per inspector per day for traditional and HeadLight processes. Table 2-6 shows the fraction of observations that reference a specific time and/or location.

Table 2-4. Composition of Observation Entries

	WSDOT	MnDOT	TxDOT	Total
Number of inspectors	6	9	9	**24**
Observation Type				
Photo	778	1,025	460	**2263**
Video	13	45	25	**83**
Text	441	101	364	**906**
Equipment	366	22	841	**1,229**
Personnel	206	45	419	**670**
Temperature	1	7	0	**8**
Weather	412	812	572	**1,796**
Start/Stop	4	68	73	**145**
Material	3	2	0	**5**
Total	**2,224**	**2,127**	**2,754**	**7,105**

25
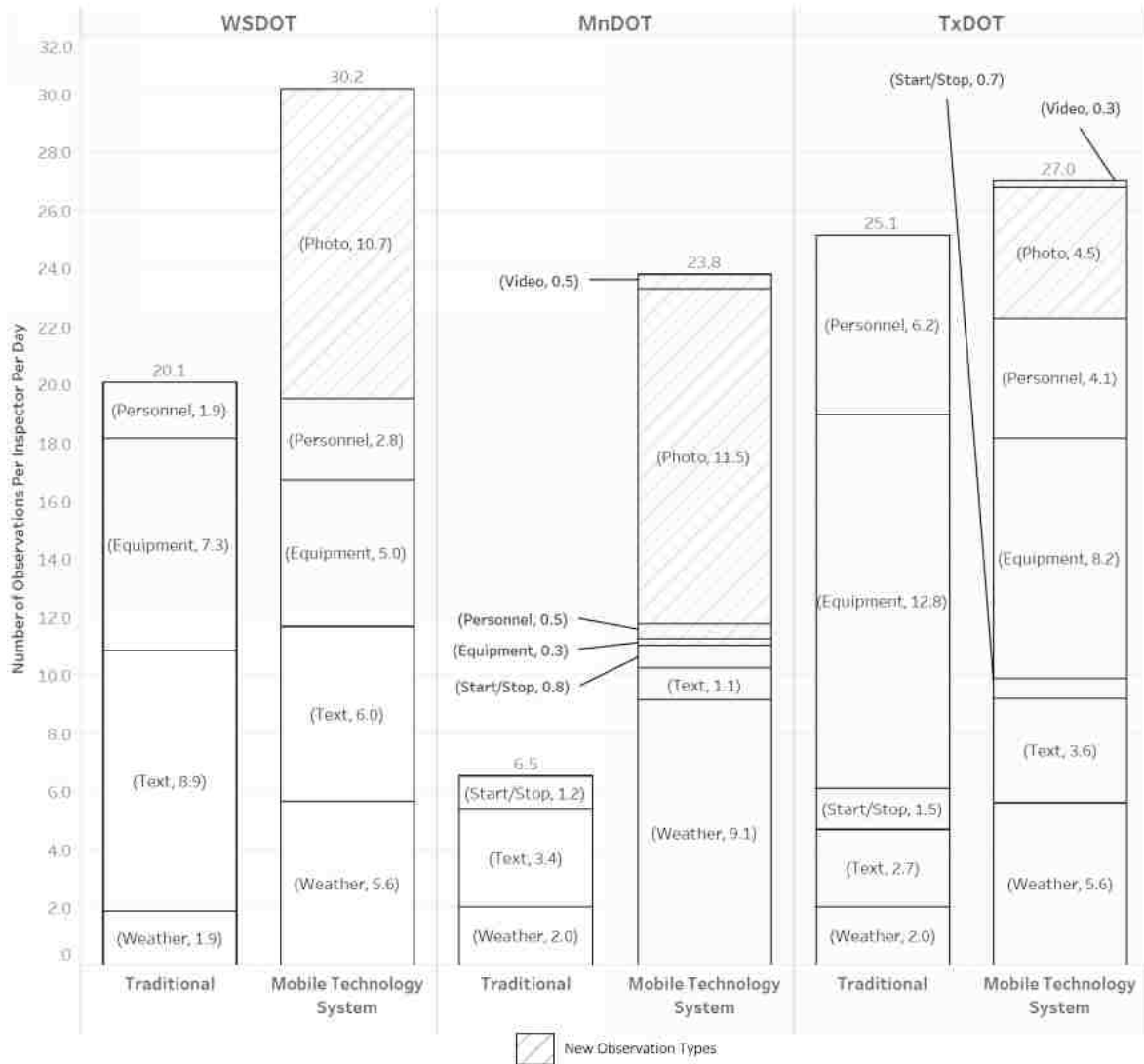
Figure 2-3. Composition of observation entries.

Table 2-5. Average Number of Observations Made per Inspector per Day[a]

DOT	Traditional Process[b]	HeadLight Process	Factor[c]
WSDOT	20.1	30.2	1.5
MnDOT	6.5	23.8	3.7
TxDOT	25.1	27.0	1.1
All Agencies	**17.2**	**27.0**	**2.1**

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 Process / Traditional Process = Factor

26

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Table 2-6. Fraction of Observations that Reference a Specific Time and/or Location

DOT	Time Associated with Observations		Location Associated with Observations[a]	
	Traditional Process	HeadLight	Traditional Process	HeadLight
WSDOT	50.4%	100%	1.8%	100%
MnDOT	2.7%	100%	6.1%	100%
TxDOT	0.8%	100%	18.0%	100%

Notes:

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

2.5.2.1 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 questions) 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.

2.5.2.2 Percentage of Daily Inspection Reports Submitted Within 24 Hours and 72 Hours

Direct measurements of WSDOT daily inspection report submission times revealed that using the traditional 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. Submission times for MnDOT and TxDOT were not accessible so only WSDOT data are reported.

2.6 Discussion

2.6.1 Productivity

DOTs in this pilot project achieved an average time savings of 1.59 hours per inspector per day by using the mobile technology system. The time savings came from performing tasks such as documentation and administrative duties as well as reduced travel. This equates to a productivity gain of 25% for the activities monitored by this study.

This outcome of increased inspector productivity can be scaled up and interpreted to provide information more relevant to higher-level DOT business practices and decisions. For instance, increased inspector productivity can be seen as an increase in the capacity of a DOT workforce without requiring

additional staff; in other words, an improvement in workforce efficiency (Table 2-6). Furthermore, multiplying the virtual gain in workforce by annual salary can represent the additional value gained from use of mobile technology for project inspection. However, 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), and (3) the potential for mobile technology to enable future value added processes/features.

Table 2-7. Potential Workforce Multiplier from Mobile Technology Applied to Project Inspection

DOT	Current Project Inspector Workforce	Workforce Multiplier Based on HeadLight Use[a]	Virtual Gain in Workforce[b]	New Virtual Workforce[c]
WSDOT	397	1.23	91	488
MnDOT	250	1.26	65	315
TxDOT	1,092	1.25	273	1,365
All	**1,739**	-	**429**	**2,168**

Notes:
   a. From Productivity gain assuming an 8-hour day in Table 2-3.
   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.

2.6.2 Data Quality

Project inspectors using the mobile technology system collected and shared an average of 2.1 times more inspection information (Table 2-4), and all observations contained time/location metadata.

The mobile technology system showed a larger variety of observation types compared to observations collected using traditional 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 traditional methods that did not included photo observations directly into the reports.

Inspectors using the mobile technology system provided more complete data as it automatically captured the date, time, and location of each observation entry (Table 2-5). The results of a metadata analysis indicated that the traditional process often missed time/location information or such information was imprecise. The consistency of the inspection information improved in two ways for inspectors using the mobile technology system: (1) automated inclusion of inspection information eliminated the potential for inspectors to record incorrect information, and (2) the elimination of

duplicate information across traditional data sources (e.g., photo and video files, daily reports, observations).

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

2.6.2.1 Transcription, Duplication, and Devices
Compared to the traditional process, the mobile technology system 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.

2.6.2.2 Information Availability
In the interviews, project engineers and management said with the traditional processes they 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 person at the project site), or, if it was available, was inefficient due to some of the content being hard to read.

2.6.2.3 Centrality, Security, and Searchability
The mobile technology system 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 traditional 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.

2.6.2.4 Multiple Uses of Collected Data

A key component to collecting project inspection information with the mobile technology system 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. Therefore, individual data, collected once, can be used multiple times throughout a DOT, and over the entire life of an infrastructure asset.

2.6.3 Technology Considerations

While the researcher was on site providing technical support to the participants throughout this study, several notable hardware and software considerations were observed. Mobile devices, although rapidly changing in form and capabilities, present several reliability issues when used in a construction environment. Several inspectors experienced their devices shutting off to protect the battery and other sensitive mechanics from excessive outdoor temperatures. The device, outfitted with a waterproof casing, was placed in a near-by lake to cool the device down which restored its functionality. Other issues encountered include screen-glare from the sun and cellular and data reception issue on projects in remote locations.

In terms of software considerations, reliability and synchronization issues were observed. Some participants reported that they encountered reliability issues, such as glitches and technical bugs, during the early phase of the pilot program. These reliability issues were reported to the technical support team and were generally addressed through continuous updates of the software. The availability of the technical support team was critical in maintaining project inspection operations and managing user resistance. Temporary synchronization issues of field data and reports were also encountered when inspectors moved from areas between good and poor cellular and data connectivity. Although not specifically measured in this study, this can result in delayed dissemination of data collected by inspectors.

2.7 Conclusions and Recommendations

This paper describes a pilot project that measured the impact of a using a mobile technology system for DOT project inspection. The pilot project compares the traditional project inspection process with the mobile technology inspection system for three DOTs (WSDOT, MnDOT, and TxDOT). Two general evaluation metrics were compared: productivity and data quality. While the scope of the pilot project was limited to certain 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 such as Contractors and Construction Engineering and Inspection (CE&I) firms, (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 study are:

1. **Project inspectors using the mobile technology system significantly increased their productivity without increasing their work hours.** Completing inspection reports, reduced travel time, and searching for information using the mobile technology system provided an average overall time savings of 1.59 hours per day per inspector.

2. **Project inspectors using the mobile technology system collect more and a larger variety of inspection information.** Project inspectors collected and shared 2.1 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 system provide more complete and consistent data.** All mobile technology observations are tagged with time/location metadata, and inspector daily reports are automatically generated from daily observations eliminating omission and transcription errors. Also, the duplication of information across traditional data sources is eliminated.

4. **The use of the mobile technology system improved the timeliness of inspector daily report submissions.** Compared with traditional processes, the mobile technology system 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 system enabled improved accessibility of inspection information throughout the project office.** Compared to traditional processes, the mobile technology system 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 system provided data centrality, security, and searchability.** Compared to traditional processes, information collected using the mobile technology system 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 system can be viewed as a workforce multiplier.** Based on measured productivity gains, the inspectors using HeadLight experienced a 25% increase in productivity. 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).

Recommendations for future work include:

1. **Expand research scope to 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 the mobile technology system 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 system was used in place of traditional 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 traditional 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 traditional processes.

As other technology sectors have shown (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 develop new applications never envisioned or possible with traditional processes.

2.8 Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request.

2.9 Acknowledgements

3.0 Factors Influencing the Adoption of Information Technologies for Public Transportation Project Inspection: A WSDOT Case Study

3.1 Preface

The efficiency gains and data quality improvements discussed in Chapter 2 provides some encouraging findings and justifications for DOTs to adopt cloud-based project data management systems. Although numerous other studies have found that the construction industry can benefit from adopting modern technologies (Asbahan and DiGirolamo 2012; Bowden et al. 2005; Valdes and Perdomo 2013), the adoption of these tools has been challenging to the industry (Arnold and Javernick-Will 2013; Dossick and Sakagami 2008; Erdogan et al. 2008; Ozorhon et al. 2013), and organization-wide adoption of technology have experienced high rates of failure (Burnes and Jackson 2011; Choi and Ruona 2011; Kotter 1995). This chapter examines the importance of organizational change management activities and how it affects the adoption of modern technology.

As of October 2018, the study described in this chapter has been accepted for publication in the upcoming Transportation Research Record (TRR) journal.

3.2 Abstract

This paper presents a case study of the organizational change process associated with the Washington State DOT's (WSDOT) year-long research program that implemented a cloud-based mobile project inspection application to 18 project engineering offices (PEO) across the state. Ultimately, 4 out of the 18 PEOs decided to adopt the new technology. Data from semi-structured interviews and a user study conducted two months after implementation are used to identify organizational change strategies used by WSDOT, and how those relate to ideas form the general literature on change management. The loss of upper management program leaders, inadequate communication and training to prepare personnel for the change, and policy and procedural uncertainties in integrating the change with other systems and operations were found as factors that may have influenced the outcome of the program. While this paper focuses on one DOT's efforts, many DOTs have similar organization structure and implementation efforts, and the findings and lessons learned can serve as a representative model for how such implementation might best be accomplished in a DOT and how that might differ from traditional change management guidance.

3.3 Introduction

State departments of transportation (DOT) use a mixture of manual and electronic methods in collecting project inspection data (Shah et al. 2017). Electronic methods are commonly used to store and manage the data, but the field personnel are still generally relying on collecting information using a paper-based method (Shah et al. 2017; Taylor and Maloney 2013). Because the number and complexity of infrastructure projects managed by DOTs have steadily increased while their workforce shrinks (Jagars-Cohen et al. 2009; Mostafavi et al. 2013; Taylor and Maloney 2013; Warne et al. 2003) DOTs are searching for ways to make their operations, including project inspection and management, more efficient and better able to handle the multitude of associated data.

Numerous studies have identified modern technologies, such as mobile devices and cloud-based data management applications, as able to improve productivity and workflow efficiencies by replacing the paper-based method of collecting DOT inspection data (Asbahan and DiGirolamo 2012; Bowden et al. 2005; Valdes and Perdomo 2013). However, adoption of these tools has been challenging in the construction industry (Arnold and Javernick-Will 2013; Dossick and Sakagami 2008; Erdogan et al. 2008; Ozorhon et al. 2013) and organization-wide adoption of technology have experienced high rates of failure (Burnes and Jackson 2011; Choi and Ruona 2011; Kotter 1995). Literature suggests the lack of available mobile and cloud-based applications designed specifically for DOTs (Taylor and Maloney 2013) and limited studies on technology implementation in large organizations (Erdogan et al. 2014; Lines et al. 2016; Sutanto et al. 2008) may be impediments to agency-wide modern technology adoption.

While the technology itself is certainly important to successful adoption, the process that an organization uses to implement the technology is likely more important. For instance, Wilkinson (Wilkinson 2005) states that 80 percent of new technology implementation depends on addressing the personnel and process issue, while 20 percent is related to technical aspects. Therefore, in order to fully understand what makes such adoptions successful or not, it is worthwhile to examine not only the technology, but also the process of changing itself.

3.4 Scope

This paper presents a case study of the change process associated with the Washington State DOT's (WSDOT) year-long, large-scale implementation of a cloud-based mobile project inspection application developed and deployed through its own research project. The focus is specifically on the implementation process itself and not the technology, with the intent of identifying key organizational

change ideas that influence success at a DOT, and how those relate to ideas from the general literature on change management. Current construction literature provides limited studies of such efforts; especially those that focus on the DOT perspective. Data for this study come from semi-structured interviews as part of a user study conducted two months after implementation. While this paper focuses on one DOT's effort, other DOTs may have similar organizational structures and implementation efforts, and the findings can serve as a representative model for how such implementation might best be accomplished in a DOT and how that might differ from traditional change management guidance.

3.5 Organizational Change Management Background

This section provides a background on organizational change management and the key factors that influence outcomes.

3.5.1 Organizational Change Considerations

Organizational change is defined as changes made to improve individual development and the performance of the organization (Choi and Ruona 2011; Erdogan et al. 2014). Organizational change is generally an adaptive response to (1) external factors, such as the availability of new technologies or changes to legislation; and (2) internal factors, such as changes in organizational values and changes in technical systems (Erdogan et al. 2014). Recently, DOTs have been impacted by a series of external and internal factors that include fluctuations in funding levels, changes to how infrastructure projects are funded, changes to personnel job responsibilities, advancements and availability of technology, and high levels of staff turnovers (Taylor and Maloney 2013). These factors have particularly affected personnel involved in the construction of highway infrastructure, which constitute a large portion of the DOT's total budget (Taylor and Maloney 2013).

The use of modern information technologies, such as mobile devices and cloud-based information systems, has been found to provide construction inspection personnel with a more efficient way to collect, store, and disseminate inspection data and provide timely access of information needed by onsite personnel (Asbahan and DiGirolamo 2012; Bowden et al. 2005; Valdes and Perdomo 2013; Yamaura et al. 2015). Most DOTs are currently using a mixture of paper-based and electronic processes for project inspection tasks (Shah et al. 2017), and there is substantial interest in continuing to adopt more modern technology to improve personnel productivity and workflow processes. DOTs that have experimented with the use of modern technologies have reported difficulty in fully adopting these technologies and their required changes to their systems and processes (Taylor and Maloney 2013). This

issue is also prevalent in the general construction industry (Arnold and Javernick-Will 2013; Dossick and Sakagami 2008; Erdogan et al. 2008; Lines and Vardireddy 2017; Won et al. 2013).

Other industries have also reported difficulties in implementing organizational change. Research in the organizational change field has estimated that two-thirds of organizational change efforts are unsuccessful (Beer and Nohria 2000). The high failure rate has most often been attributed to user resistance and the way the change is implemented (Kotter 1995; Lines et al. 2016). Erdogan et al. (2014) and Lines et al. (2016) have cited Wilkinson (Wilkinson 2005) stating that 80 percent of successful implementation of new technology depends on addressing the personnel and process issue and 20 percent is related to addressing the technical aspects of the change. The following literature review on organizational change is grouped into these two categories.

3.5.1.1 Technology Issues

Some potential issues with implementing new technology include its ease of use and how well it is integrated with the existing information technology (IT) system. In construction, project inspectors are responsible for collecting large amounts of inspection information on a daily basis. The timely and accurate collection of this data is crucial in tracking cost, schedule, and material aspects of the project. If the implemented technology is complicated and time consuming to learn, the user often reverts to the traditional process (Dossick and Sakagami 2008). Lack of integration between the new technology and the existing IT system has also been identified as a factor in unsuccessful implementation efforts. Technology that is implemented in an ad-hoc manner that is not well integrated in to the existing system becomes marginalized and underused (Arnold and Javernick-Will 2013; Dossick and Sakagami 2008).

3.5.1.2 Personnel and Process Issues

Studies in organizational change identify a lack of personnel readiness as a significant factor contributing to user resistance and failed change efforts (Choi and Ruona 2011; Kotter 1995; Sutanto et al. 2008). For personnel to be ready to be a part of the change, they must believe in the change and that it can be successfully implemented (Choi and Ruona 2011; Lines et al. 2016). Organizations that do not provide adequate communication informing change participants of the reasons behind the change, how they are affected by the change, and the vision and goals of the change, will experience higher rates of user resistance regarding the change (Lines et al. 2016).

Another factor contributing to failed change implementations is the lack of consistent leadership from management personnel. Effective leaders that visibly participate in the change tend to help sustain

participant involvement, improve performance and productivity, and reduce uncertainty and resistance to the change (Dallavalle C. 1991; Ozorhon et al. 2013; Sanders Steve R. and Eskridge W. Frank 1993). They are critical in receiving feedback from participants and have the authority to make changes to address concerns. Inadequate communication and buy-in from personnel in leadership roles can lead to prolonged employee denial and resistance, jeopardizing the success of the change (Armenakis and Bedeian 1999; Dallavalle C. 1991).

Opposition to the change can occur at different levels of the organization's hierarchy and is best addressed by creating a guiding group comprised at each level of the hierarchy (Kotter 1995). Implementation of new technology will result in the decline of participant performance during the early phase of the change when participants are getting accustomed to performing their daily tasks in a new way (Nikula et al. 2010).

3.5.2   Organizational Change Process

Studies, both within and outside of the construction industry, have identified procedures to help organizations guide their employees through change towards successful acceptance. Table 3-1 summarizes significant change management procedures and factors found in management studies.

Table 3-1. Procedures and Factors for Successful Change Management from the Literature

Factors	Significance	Studies
Establish the need to change	Recognize the need to change by examining internal and external factors affecting the performance of the organization. Propose a solution and investigate its feasibility for adoption. Consider impacts on business processes, technology constraints, and investment benefits.	• Dallavalle. 1991 • Kanter et al., 1992 • Kotter, 1995 • Sutanto et al., 2008 • Erdogan et al., 2014
Managerial/guiding group commitment and participation	Lack of managerial commitment result in employee alienation, resistance, increased absenteeism, loss of productivity, and failure. Managers should be proactive rather than reactive to achieve long term goals. They must also be able to get employee buy-in. Creating a guiding group comprised of personnel from each level of the hierarchy can help communicate the need to change and help personnel become ready to be a part of the change.	• Dallavalle, 1991 • Kanter et al., 1992 • Sanders and Eskridge, 1993 • Kotter, 1995 • Armenakis and Bedeian, 1999 • Sutanto et al., 2008 • Erdogan et al., 2008 • Ozorhon et al., 2014 • Matthew at al., 2015 • Lines and Vardireddy, 2017
Communication to promote	Early and frequent communication of change and the reasons behind it helps build awareness throughout employees and reduces uncertainties. Important to	• Dallavalle, 1991 • Kanter et al., 1992

awareness and feedback	receive and address feedback from employees to give them a sense of empowerment and promote synergy in change.	• Sanders and Eskridge, 1993 • Kotter, 1995 • Erdogan et al., 2014 • Matthew at al., 2015 • Lines and Vardireddy, 2017
Plan to manage resistance	Resistance is an appropriate behavior. Manager's role is critical in listening to employee concerns and solving problems or compromising on issues.	• Dallavalle, 1991 • Armenakis and Bedeian, 1999 • Bovey and Hede, 2001 • Erdogan et al., 2008 • Matthew at al., 2015
Tailor processes and policies to meet specific needs	Participants that tailored processes to meet their own needs were consistently successful through the change efforts. Those who took programs verbatim from others and tried to force fit them into their processes encountered more difficulties and were less successful. Agencies should modify existing policies and standards affected by the change to clarify organizational expectations.	• Sanders and Eskridge, 1993 • Kotter, 1995 • Erdogan et al., 2014 • Matthew at al., 2015
Training	General and continuous training to prepare employees for change and prevent reversion to old condition.	• Sanders and Eskridge, 1993 • Erdogan et al., 2014 • Lines et al., 2016 • Lines and Vardireddy, 2017
Measurement and evaluation of change	Bench marking the current state and developing the change vision helps create metrics in which the success of a change can be measured.	• Sanders and Eskridge, 1993 • Kotter, 1995 • Sutanto et al., 2008 • Lines and Vardireddy, 2017

More than half of the factors shown in Table 3-1 are methods that help manage resistive behaviors from employees. Lines et al. (2016) classified resistant behaviors into three categories:

- **Active Resistance.** Resistance in open form that directly challenges the change effort. Specific acts include employees ridiculing and finding fault with change, resigning or leaving, and sabotaging change effort (Bovey and Hede 2001; Fiedler 2010).

- **Passive Resistance.** Directly observable but submissive and tractable forms of opposition. Specific acts include reluctant compliance, procrastination, and consciously avoiding participation (Bacharach et al. 1996; Bovey and Hede 2001).

- **Inadvertent Resistance.** Involuntary behaviors that negatively impact the success of the change effort. Inadvertent resistance are acts where it is unclear whether resistance was the intent of

the employee. Examples include employees reverting back to old conditions due to lack of understanding and training on change, difficulties letting go of traditional methods, and misguided use of new conditions (Emiliani and J. Stec 2005; Molenaar and Gransberg 2001).

In summary, systematic change management procedures are well-established and often reported. Research has identified the key factors influencing the outcome of change efforts, including: managerial commitment and participation, communication, managing resistance, tailoring processes, training, and measurement/evaluation. Importantly, resistance from employees are an expected and appropriate behavioral response that can be properly managed.

3.6 WSDOT Background

From 2000 to 2010, the total lane-miles managed by state DOTs increased by an average of 4.1% while their in-house personnel available to manage them decreased by an average of 9.78% (Taylor and Maloney 2013). Across the country DOTs are facing the challenge of doing more with less resources. WSDOT reduced its transportation engineers and technicians by 26.8% from 2010 to 2015 (The PFM Group 2016). Faced with such reductions, WSDOT engaged in a multi-stage research effort to investigate, and, if warranted, develop and deploy a cloud-based mobile project inspection application to improve personnel productivity and the inspection workflow processes (Snow et al. 2013). Development, done with Seattle-based company Pavia Systems, Inc., produced software called "HeadLight", which was piloted in 2014 for 3 months on 7 projects with 6 inspectors and 2 project management personnel (Yamaura et al. 2015). The pilot program found productivity and data quality improvements in project inspection and management tasks which led to a large-scale implementation of the technology in 2015. This paper focuses on the 2015 implementation program, and specifically how the technology was implemented and the associated organizational change.

3.7 Method

This paper analyzes the organizational change activities in implementing HeadLight. The year-long research program conducted on a trial basis began in April 2015 and involved 18 WSDOT project engineering offices (PEO) and 33 projects (about 20% of active projects during a typical summer construction season) across the state (Figure 3-1). Ultimately, 14 out of the 18 PEOs decided to revert to their traditional project inspection practices, and this method identifies the change management process and possible areas for improvement based on two semi-structured interviews and a post-implementation use study.
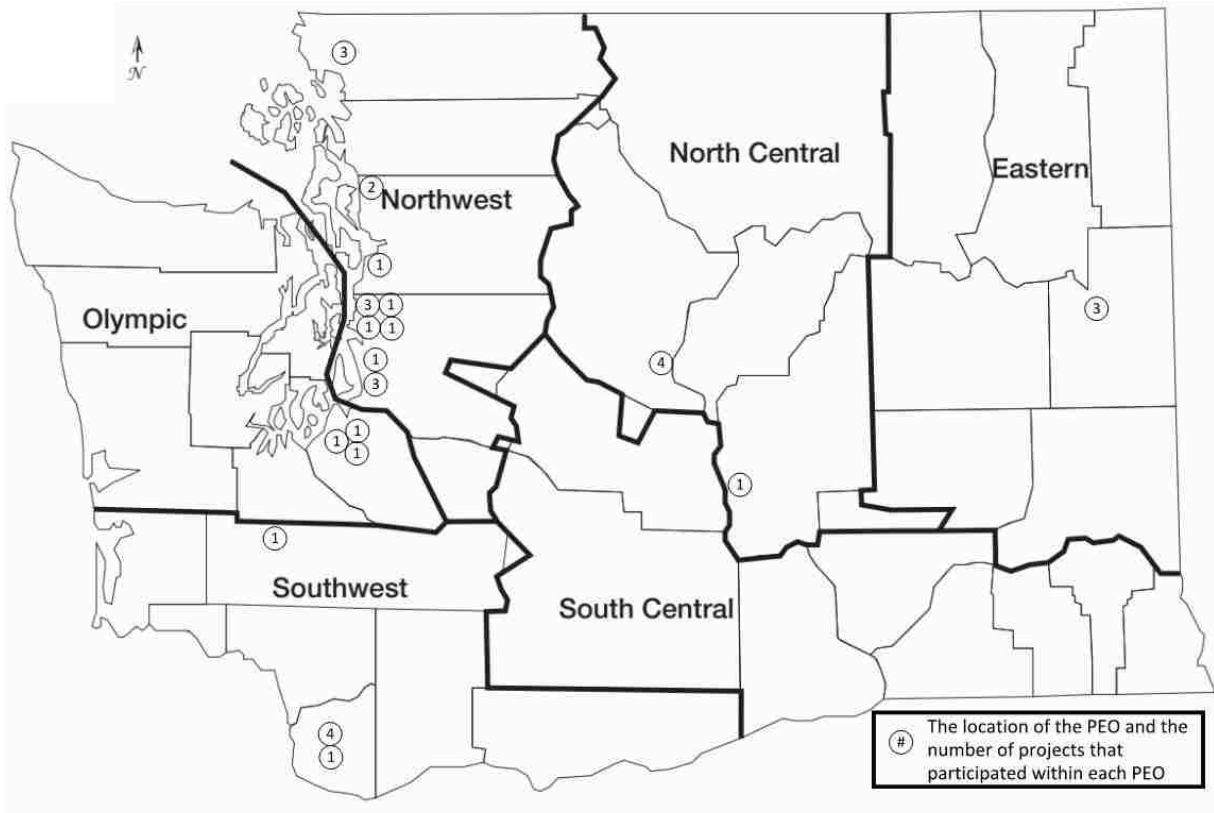
40

Figure 3-1. Locations and number of projects represented in this study.

A timeline and description of WSDOT organizational change activities were identified by conducting two interviews: one with a WSDOT executive sponsor of the implementation program, and the other with the Pavia Systems project manager for the software development. These two individuals were personally involved in the planning and implementation stages and have first-hand knowledge of the activities conducted in the program. The intent of the interview was to establish the timeline and facts of what occurred. Organizational change activities identified through these interviews were compared to those show in Table 8.

WSDOT also conducted a user assessment study two months into the deployment period in which qualitative data (narratives) from participant interviews were documented. Out of the 232 WSDOT personnel that participated in this implementation program, 136 of them participated in the user assessment study. A total of 88 written narratives were documented (some participants were interviewed together in one session). The user assessment interviews were conducted face-to-face at the PEO field offices. Table 3-2 shows the breakdown of the PEO, region, number of projects, and number of interview participants that were involved in this study. The interviews consisted of open-ended questions for both field and office users that were asked to determine the user's interaction and

frequency of use, the extent of how they have been using it, and their feedback on areas of improvements.

PEO	Region	Number of Office Users	Number of Field Users	Total Number of Users	Number of Projects	Number of Interview participants
1	Northwest	6	6	12	3	10
2	Northwest	3	7	10	1	7
3	Northwest	11	4	15	1	6
4	Southwest	8	6	14	4	11
5	Southwest	8	2	10	1	8
6	Northwest	8	4	12	3	8
7	Northwest	11	4	15	3	7
8	Olympic	13	11	24	1	7
9	Olympic	12	8	20	1	4
10	Northwest	10	3	13	1	12
11	North Central	2	1	3	1	2
12	Northwest	9	3	12	1	7
13	Eastern	8	5	13	3	11
14	Northwest	7	2	9	2	7
15	Olympic	4	1	5	1	3
16	Northwest	13	12	25	1	14
17	North Central	6	3	9	4	5
18	Southwest	7	4	11	1	7
TOTAL		**146**	**86**	**232**	**33**	**136**

The narratives from these interviews were analyzed and qualitatively coded using the Dedoose qualitative data analysis web application. The coding process followed an inductive coding method to let the concepts emerge from the narrative without any preexisting set of codes or ideas (Miles et al. 2013). The codes were found to fit into two major concepts: issues and resistance. The replicability and reliability of the code identification process was validated through an intercoder reliability test with an independent university researcher experienced with qualitative coding methods. The results of the organizational change evaluation and the qualitative data analysis from the user assessment interviews are used to determine factors that may have influenced the outcome of WSDOT's project inspection technology implementation program.

We recognized that decisions made during this technology deployment effort were likely influenced by many factors external to the study such as social and political pressures, organizational directives not

related to the change, or other perceived necessities. We make no judgement on the appropriateness of decisions, nor do we comment/speculate on conditions beyond the scope of study that may have influenced those decisions.

3.8 Results

3.8.1 Organizational Change Activities

This section describes the organizational change activities that were performed by WSDOT during the implementation. The results are grouped by the organizational change process recommendations found in literature (Table 3-1). This section only catalogs activities and the extent to which they were done (or not); analysis is left to the Discussion section.

3.8.1.1 Establishing the Need for Change

The need to establish a more efficient project inspection process was documented in a 2013 State Pavement and Technology Consortium research project that discussed how technology can impact project inspection practices for WSDOT and the Texas DOT (Snow et al. 2013). The report cites limitation on project funding, the need to provide more efficient tools for inspection personnel, excessive time spent by inspectors creating inspection documentation and administrative procedures, and the limited specifications and guidelines on inspection documentation resulting in the collection of inconsistent and variable inspection data as issues that can be addressed by implementing modern technology (Snow et al. 2013).

3.8.1.2 Selecting Program Leaders and Implementation Team

The technology implementation program was initiated at the WSDOT Headquarter level through a research project. The State Materials Engineer and the State Construction Engineer were considered sponsors and actively supported the program. An implementation team consisting of WSDOT personnel from all levels of inspection operations was not formed. The WSDOT IT Department was consulted but not involved with the development and implementation of the program because it was developed by a consultant.

3.8.1.3 Developing and Communicating the Change

One month before the technology deployment, the technology implementation was communicated in two ways. First, the WSDOT implementation sponsors discussed the technology and its potential impact with five Project Engineers working in five separate PEOs. These discussions introduced the coming change but did not establish a clear vision or guidelines on how it would directly impact project

inspection operations. Generally, project engineers expressed excitement about the program and were willing to implement the change. The second communication was conducted via email sent out to management personnel representing all participating PEOs. The email contained information on the training and implementation schedule but did not clearly address how the new technology was to be used and how the inspection documentation procedures would be affected by this change. It was also not made clear to the PEOs and the participants that this was a research project conducted on a trial basis.

3.8.1.4   Modify Policy and Procedures to Facilitate the Change

There were no changes to the existing manuals that describe the inspection documentation procedures prior to the technology implementation. Although procedures on collecting and reporting inspection data using the new technology were provided on the first day of the technology deployment, clear procedures on how and where to accept, store, and disseminate the data were not provided to the participants.

3.8.1.5   Conduct Training

A half-day in-class training session was provided to the field users on the day of the technology deployment. The session discussed the vision and reason for the technology implementation and provided training on using the technical aspects of collecting data and producing field documentation. Onsite training was also conducted for the field users after the in-class session. A separate in-class training session for office users, discussing the vision and reason for the technology change and training catered to the office users, was provided a week after the field training session.

3.8.1.6   Evaluating the Change and the Change Process and Standardize New Approach

A user assessment study conducted two months into the deployment evaluated how the users were interacting with the technology and system, need for additional training, and policy and procedural issues, and user resistance. In addition, feedback from the program participants were sent directly to the two WSDOT program sponsors by the PEO managers on a monthly basis. Issues brought up in the feedback were addressed by the program sponsors. However, feedback monitoring was discontinued three months into the deployment because the two program sponsors were rotated into different organizational roles and were not able to continue sponsoring the program. This was a major setback as the program was not clearly communicated towards upper management, mainly because it was a trial-based research project.

3.8.2 Issues and Resistance Identified from the User Assessment Study

The user assessment interview narrative analysis found two major code themes: issues and user resistance. These major themes were further classified into nine subcategories for issues and six subcategories for user resistance. Table 3-3 shows the number of times the interview participants mentioned them during the interviews. The intercoder reliability test resulted in Cohen's kappa values of 0.89 and 0.78 for the codes in the issues and user resistance category respectively. These values signify substantial agreement between the raters (McHugh 2012). Three iterations of this test were conducted. Each iteration underwent revisions of the code titles and its definitions to better describe the themes found in the narratives. The Cohen's kappa values reported here were obtained from the third intercoder reliability test.

Table 3-3. Number of Times Issues and User Resistance Were Mentioned by Various Participants in the User Assessment Study

Themes and subcategories	Inspector (40)[a]	Chief Inspector (10)[a]	Office Engineer (19)[a]	Project Engineer (14)[a]	Mixture[b] (5)[a]	Total (88)[a]
Issues						
The need for more training opportunities	6	4	5	9	4	28
Software Reliability Issues	19	1	2	2	2	26
Document Format Issues	2	4	3	4	4	17
Hardware Reliability Issues	12	3				15
Implemented Technology on Non-Active Project	5	2	1	2	1	11
Lack of communication from leadership in using new technology	3	2	2	1	1	9
Unclear agency policy regarding the new documentation process	1	2	2	1		6
Technology implemented on a project that has already started		1	1			2
Technology not implemented on all projects			1			1
User Resistance						
Reluctant Compliance	6	2	4	2		14
Complete Reversion	3	1	5	1		10
Did Not Participate in Program	1		5	2		8
Occasional Reversion	6			1		7
Open Criticism	4					4
Restricting Education	2					2

Notes:
a. Number of interview narratives analyzed for the corresponding personnel role.
b. More than one personnel role type included in the interview session; roles of those making specific comments were not identified

3.9 Discussion

This section evaluates the activities that were conducted during the technology implementation and provides some lessons learned. It also discusses the major issues and user resistance expressed by the four inspection personnel roles shown in Table 3-3.

3.9.1 Lessons Learned

3.9.1.1 Leadership and Implementation Teams

The planning phase of the technology implementation program relied heavily on the leadership of two WSDOT upper management personnel. As discussed previously, organizational change guidance recommends a group of individuals from all levels of the organization's hierarchy to develop a shared understanding of the existing issues to create commitment and momentum to achieve the desired changes. Directly involving personnel familiar with the different aspects of project inspection from the participating PEOs can lead to increased awareness of the program and address feedback and concerns prior to the deployment of the technology.

The interview with the upper management sponsor indicates the WSDOT IT department was not involved in the development of the new technology, which may have contributed to issues integrating HeadLight data with existing systems. In some cases, inspectors and office engineers performed duplicative work to ensure that all relevant information was also entered into the existing system. These types of integration issues, identified as a major barrier for this program, are common and must be actively addressed throughout the program.

Leadership involvement was also an issue: WSDOT rotated their executive leaders (construction, design, and maintenance) into new roles three months into the initiation of the program. The two program sponsors were not able to continue to lead the deployment in their new roles. After the new role assignments, the deployment continued with less direction from upper level management and no major decisions or changes were made to address feedback and issues from the participants. These findings corroborate previous studies that have identified the lack of involvement from upper management as a significant barrier to technology implementation programs (Dossick and Sakagami 2008; Ozorhon et al. 2013).

3.9.1.2 Communication

Participants in the user assessment study that identified a lack of communication about the program typically did so by saying they were not familiar with the program, they wanted more direction on how to use the new technology, expectations were not clear on how the technology fits in with their current inspection system, and performed inspection tasks using both the new and traditional methods since clear directions were not provided to them. The mass email sent to the participants did not contain information regarding the reason for change, the disadvantage of continuing with the current inspection practice, clear guidelines on the capabilities and limitations of the new technology, or that the implementation was part of a research program. The new technology was developed to perform a portion (but not all) of the project inspection work and its scope of use was not explained prior to deployment. Much of the literature indicates that uncertainty and user resistance decrease with early and frequent change related communication (Armenakis and Bedeian 1999; Lines et al. 2016).

3.9.1.3 Policy and Procedural Changes

The interview with the consultant project manager found that developing the new technology was challenging. The traditional field documentation that was meant to be replaced by the technology had a variety of formats across PEOs which created difficulties in specifying the universal format for documents created using the new technology. This is reflected in Table 3-3, which shows many participants mentioned document format issues during the user assessment study. Differences from the traditional format used by some of the PEOs, created legitimacy concerns. Some approvers of these reports were accustomed to physically signing paper to show acceptance and were unsure about policies related to electronic approvals of document approval. Some participants mentioned being audited during the implementation program and the auditor was not clear on how to address content created using the new technology. Policy and inspection documentations were not revised to address these issues which demonstrates the need for continued upper management and empowered personnel that have the authority to address barriers as they arise. Based on the literature, forming guiding groups across the state to create a set of standard procedures directing the use of the new technology and all functions associated by the change may reduce the time and effort needed for personnel to become accustomed to the change.

3.9.1.4 Training

The need for more training was the most frequent issue mentioned in the user assessment study. Out of the participants that mentioned the need for more training, 28 percent also mentioned issues with

document format issues. Inspectors and personnel approving field documentation expressed the need for more training to create field documentation that were more representative of what they were used to creating. This finding corroborates studies that found the need for more training as a significant barrier to technology adoption (Erdogan et al. 2008).

Planning training sessions can be challenging and costly for DOTs when multiple PEOs across that state are involved. Orflay et al. (Orfaly et al. 2005) point out that the availability and accessibility of training is greatly improved when the trainer is stationed on site. Additionally, Orfaly et al. (Orfaly et al. 2005) indicate that this practice provides more credibility to the training as the trainer is a known and trusted member of the group.

3.9.2 Issues and User Resistance by Role

3.9.2.1 Inspectors

The most frequent issues mentioned by inspectors were software and hardware reliability issues. This differs from the literature, which generally contend that a majority of issues are personnel and process issues rather than technical issues (Erdogan et al. 2014; Lines et al. 2016). Some examples of software issues include data-server synchronization issues, technical bugs, and temporary loss of collected data. Data reception issue and screen glare were the most common hardware issues mentioned. Software issues were not significantly linked to user resistance behaviors. The software was frequently updated to address user issues which may explain how these two factors were not correlated. Among the inspectors that mentioned hardware issues, approximately 35 percent of them expressed user resistance in the form of occasionally reverting to collecting inspection data in a paper notebook. Along with reluctant compliance, occasional reversion was one of the most frequently observed resistance types within inspectors. Inspectors that expressed occasional reversion mentioned that they reverted to taking notes in their field notebook when they needed to capture data in a timely manner and were still getting familiar with using the mobile device. Inspectors that were reluctantly participating in the program mentioned that it was difficult to get used to using mobile devices. Based on the literature, continuous training and feedback sessions conducted by guiding groups and management personnel might help identify and address the personnel and process issues throughout the program to managing uncertainties and resistive behaviors.

3.9.2.2 Management

The need for more training and document format issue were two common issues stated by chief inspectors, office engineers, and project engineers. Their role in supervising inspectors and processing

field documentation into the inspection documentation system explains this concern. These two issues were closely related as these three roles wanted their inspectors to be trained on how to create field documentation that resembled their traditional format. Personnel concerned with the format of the field documentation expressed uncertainty on whether the field documentation created using the new technology was acceptable. They explained potential policy and legal ramifications when field documentations are not formatted correctly as they are important sources of information when contract disputes and claims arise. Based on the literature, communication from upper management and updating policy to include specific electronic methods of documentation acceptance are potential methods in addressing the concerns stated by these three roles. This can also reduce the relatively high rates of user resistance seen in the office engineer group. Office engineers that reverted to the traditional system or did not participate in the program indicated a lack of awareness and intent of the program. Some understood the program as a new system for the field inspectors and did not realize that they were also participants.

3.10 Conclusions and Recommendations

This case study examined the organizational change activities performed by WSDOT in its research project that implemented a modern cloud-based mobile project inspection technology to 18 PEOs across the state. Ultimately, 4 out of the 18 PEOs decided to adopt the new technology. The objective of this study was to examine this implementation process to identify key organizational change ideas that influence success at a DOT, and how these ideas relate to those described in existing literature on change management. The intent of this paper is to serve as a representative model for how similar implementation efforts might best be accomplished in a DOT.

Overall, the organizational change activities conducted by WSDOT generally followed the change activities referenced by organizational change management literature. The following lists the activities performed during the implementation program and discusses the degree to which each activity followed the organizational change management process in the literature.

- **The need for change was well established.** A 2013 State Pavement and Technology Consortium study conducted by WSDOT and TXDOT documented the external and internal factors that presented issues to project inspection practices, and how these issues can be addressed by implementing a cloud-based mobile technology.
- **Program leaders were selected and were committed to the implementation program, but IT was not involved.** Two WSDOT Headquarter level personnel sponsored and managed the

implementation program. In contrast to organizational change recommendations, no guiding groups were formed and the WSDOT IT department was not involved in the program.

- **The implementation program was communicated in two ways one month prior to the technology deployment.** The sponsors of the program discussed the implementation program with five Project Engineers to inform them about the upcoming changes. Emails containing deployment and training schedules were also sent out to management personnel at participating PEOs. However, as recommended by the literature, the communication did not state information such as the reason for the change, goal and vision of the change, how existing inspection practice will be affected by the change, and clear guidelines on how to use the new technology. Lack of awareness and intent of the program were mentioned as contributing factors for the relatively high rates of user resistance seen in the office engineer group.

- **Existing policies and procedures were not modified to reflect the changes resulting from the implementation of the new technology.** Implementation programs that do not modify policies and procedures to address changes in workflow processes ensuing from the use of new technology typically result in procedural uncertainty and reversion to traditional processes. Narratives from the user assessment interviews revealed that management personnel had policy and legal concerns with the new field documentation which were not addressed in the existing policies or inspection manual.

- **Training was conducted during the early phase of the program.** General training was provided to inform participants of the reason behind the implementation of the new technology and how to use it to conduct their daily tasks. This training approach varied from the literature recommendation as it did not provide continuous training throughout the program. The need for more training was identified as the most frequent issue reported by the participants (Table 3-3).

- **The sponsors evaluated the change and the change process during the early stages of the program.** Aligned with literature recommendations, the program sponsors monitored feedback from participants on a monthly basis and a user assessment study was also conducted to identify technology and workflow issues, the need for more training, policy and procedural issues, and user resistance.

The results and findings from this study present some discussion points and lessons learned helpful for DOTs planning on undertaking similar implementation efforts. These lessons learned include:

- **Consistent involvement of upper management personnel and guiding groups is crucial for a successful change program.** Technical, personnel, and process issues resulting in user resistance are appropriate behavioral responses to change. Upper management leadership and guiding groups are needed to manage these behaviors. The two WSDOT upper management program sponsors frequently reviewed and addressed feedback and issues from the program participants. When the agency rotated their upper management staff into new roles, the two program sponsors were unable to continue to lead the program. The program continued with little direction from upper level management and no major decisions and changes were made to address feedback and issues from the participants. This likely contributed to majority of the PEOs reverting to their traditional inspection practices.

- **Documentation and workflow process variations across regions or PEOs may become issues in implementing new technologies**. While new technology may be good at reproducing standard processes, those processes may not, in fact be standard to begin with. It may be true, as with WSDOT, that regions and PEOs within the same DOT perform assumed standard processes differently. If so, technology implementation will be confounded by unintended changes in process for some, which can cause additional resistance and confusion.

- **Issues in integration with other systems may be problematic.** The data and information produced and disseminated in the project inspection system were complex and affected multiple divisions outside of the general project inspection group. Although the focus of the new technology was scoped for a portion of the project inspection task, it affected other tasks such as audits, project management records compliance, and contract dispute evaluation. Some comments from the user assessment study expressed uncertainty about how to integrate the new technology and its processes to other aspects of project management functions that rely on its data and information.

- **Reliability issues can occur during the early phases of implementing new software.** DOTs developing their own software, whether inhouse or with consultants, should expect participants to encounter software reliability problems such as technical glitches and data synchronization issues during the early stages of its implementation. The technology discussed in this study, now commercialized, addressed software issues incrementally throughout this implementation program. A decline in user performance during the early stage of technology implementation efforts should be expected while users are learning to perform their tasks in a new way (Nikula et al. 2010) and technical issues are identified and resolved.

Based on the above findings and lessons learned, the following recommendations are provided.

- **The general advice found in the organizational change management literature (Table 3-1) work well for technology implementation programs conducted by DOTs.** Instances where some of the procedures were not followed or only followed to some degree resulted in negative consequences that may have contributed to the unsuccessful outcome of the implementation program.

- **Consider integration with systems and functions outside of the scope of the implementation program.** Modify policies to address procedural and administrative changes resulting from the change. Guiding groups formed at various regions/PEOs should create standard procedures that addresses these changes. Involve the IT department to create technical solutions to minimize the administrative efforts needed to integrate information into existing systems. Identify integration considerations during the pilot phase and address them prior to large-scale deployments.

- **Consider extensive training program and change readiness support when budgeting for time and cost for the implementation program.** Station trainers onsite and provide continuous training to quickly move users from the performance decline period to an improved performance state and minimize user resistance. These types of change management activities are costly and resource intensive, but this investment can lead to a meaningful process improvement and long-term operational benefits.

- **Ensure a method to obtain personnel feedback to manage resistance.** Feedback from personnel should be obtained frequently to directly monitor and manage user resistance.

4.0 Current Use of System Technology and Potential Applications of Data Beyond Construction Use

4.1 Preface

By 2018, the HeadLight system has been implemented by over 15 DOTs (city, county, and state) and construction, inspection, and engineering (CEI) firms. For over 3 years, these agencies and CEI firms have collected over 800,000 inspection observations using HeadLight. Analysis of large and diverse datasets, commonly referred to as big data analytics (Bilal et al., 2016), has helped the healthcare, retail, and other industries better understand customer needs, improve decision-making, and better predict risks (Cai and Zhu 2015). As demonstrated by these industries, analyzing the vast amounts of diverse data and information collected in HeadLight may provide DOTs with insights on project performance and support the needs of offices throughout the agency. This chapter examines the HeadLight data collected by three DOTs and explores the potential of applying the data beyond project inspection purposes.

This study is intended to be submitted for journal publication after the publication of this dissertation.

4.2 Introduction

Large amounts of data and information are produced during the construction phase of transportation infrastructure projects managed by DOTs. The construction office, comprised of personnel groups responsible for various aspects of project documentation (e.g., project inspection, change orders, materials testing, environmental compliance), generate and store data in multiple locations. Currently, DOTs do not have efficient processes and tools to exchange and process this fragmented data throughout the agency (Valdes and Perdomo, 2013; Kim et al., 2015). Much of the construction data produced is stored in either physical or digital repositories as unstructured text-based documents (Mao et al. 2006; Valdes and Perdomo 2013) that are not able to be accessed by computers or whose contents cannot be searched and processed. This method of producing and storing construction data makes it difficult to create value beyond its administrative, legal, and record-keeping purposes.

Big data analytics, defined as the analysis of large volumes of diverse datasets that are rapidly acquired (Bilal et al., 2016; Janssen et al., 2016), has been widely used by the healthcare, retail, and financial industries to better understand customer needs, improve service quality, and predicting and preventing risks (Cai and Zhu, 2015). Cloud computing technology which allows users to collect, disseminate, and analyze data by providing application, storage, and processing services connected through a real-time network (Chong et al., 2014), has been adopted by these industries to perform big data analytics.

The use of cloud computing technology in DOT construction projects can offer a paradigm shift from collecting unstructured documents located in multiple data repositories to producing structured data stored in a central location that can be presented in different ways for various users and purposes. The exchange of project data throughout a DOT's entire organization can create opportunities for new decision-making applications to better manage transportation infrastructure systems.

4.3 Scope

This study provides descriptive statistics and potential application of inspection data collected in the HeadLight system by three DOTs; WSDOT, RIDOT, and LADOTD. These DOTs were selected based on:

- **The capacity of HeadLight use**: These DOTs integrated HeadLight into their project inspection processes in different ways. WSDOT and RIDOT used HeadLight as a standalone system for a portion of inspection tasks related to the creation of daily inspection reports. Personnel manually extracted HeadLight data needed to complete other project management tasks (e.g., processing payments, determining contract working days, etc.) using traditional tools and processes. LADOTD fully integrated the HeadLight system into their traditional project management system (automatic flow of data between the two database systems). More information on the system integration methods are described in the Background section.
- **Availability of data and duration of HeadLight use**: DOTs that used HeadLight for trial purposes were not considered for this study. Trial usage of HeadLight typically involved one project with very few participants. WSDOT, RIDOT, and LADOTD implemented HeadLight on multiple projects that included multiple HeadLight users. More information on the projects and users are provided in the Methods section.

Data collected in HeadLight up to August 23, 2018 from 11 projects across these three DOTs are examined in this study. The metrics used to describe the descriptive statistics of the HeadLight data include volume, variety, and completeness of the dataset. Potential application of the HeadLight inspection dataset for asset management and environmental compliance activities are presented. A literature review, further discussed in the Background section, determined that these two activities collect data commonly collected during project inspection. For this reason, these two activities were chosen to demonstrate the potential application of HeadLight data beyond project inspection purposes. As asset management and environmental compliance encompass a wide variety of tasks, the scope for

both activities has been narrowed down to traffic safety asset management and hazardous material (HazMat) management respectively.

4.4 Background

The following section provides background discussing the capacity in which HeadLight was used for each DOT. As the integration method chosen by the DOTs can have an influence on how HeadLight is used, the traditional inspection process is briefly described to provide context on how each DOT integrated HeadLight into their project inspection workflow processes. This section also provides a general background on some of the data collected for traffic safety asset management and HazMat management activities. Identifying these data needs help determine the types of data to search for in HeadLight to demonstrate the value of inspection data for these two activities.

4.4.1 Background on HeadLight integration Approach

4.4.1.1 WSDOT Integration Approach
Traditionally, WSDOT inspectors use electronic forms designed internally through the Microsoft InfoPath software to record permanent field documentations (FHWA, 2018). Depending on the inspector, they may take notes on paper first and transcribe their notes on to the electronic forms. Others may complete the forms directly in the field using their laptop or other mobile devices. These electronic forms are managed and stored in the Microsoft SharePoint system. Supervisors and management personnel use SharePoint to review and approve field documentation submitted by inspectors. The InfoPath system stores and manages information in the form of documents or entries, not the individual data within the documents (FHWA, 2018).

WSDOT implemented HeadLight as a standalone system that substituted the workflow processes involved in recording and managing field inspection observations used to generate daily construction reports. The HeadLight database system was not directly integrated into SharePoint or other construction management systems. As a result, projects using HeadLight also continued to use SharePoint to manage work processes outside of HeadLight's scope. The data in HeadLight was not required to be integrated into the SharePoint system.

4.4.1.2 RIDOT Integration Approach
RIDOT traditionally uses the Construction Management System (CMS), a database management system developed internally in 2003, to manage project inspection information. Inspectors initially handwrite field observations in their notebook and transcribe the information into electronic forms. These forms

are printed and provided to supervisors or management personnel for review and approval. The information on the approved forms are then transcribed into respective fields in the CMS for storage and management purposes. Copies of the physical forms are filed in a filing repository (FHWA, 2016).

Similar to WSDOT's integration method, RIDOT implemented HeadLight as a standalone system. HeadLight was not directly integrated into the CMS. HeadLight data needed to complete tasks other than producing daily inspection reports were manually entered in to the CMS (e.g., processing payments, material testing, etc.).

4.4.1.3 LADOTD Integration Approach

LADOTD traditionally uses AASHTOWare's Project Site Manager (SiteManager) construction management system to electronically store and manage inspection records. Inspectors handwrite notes in a numbered field book to document construction activities and inspection observations. This information is transcribed on a physical project diary form. Supervisors collect each inspector's diary and summarizes all their information into one official daily work report form. The information in the daily work report is then entered into SiteManager. Inspector's physical field books are logged and stored by Enterprise Support Services, a LADOTD headquarter division that supports administrative and record keeping services (LADOTD, 2017).

Developers of the HeadLight system worked with LADOTD to directly integrated the servers and database systems used by HeadLight and SiteManager. Inspectors added tags, or metadata identifiers, to specific narrative observations in HeadLight to automatically direct the data into respective SiteManager fields. Daily construction reports generated and approved in HeadLight were also automatically integrated into SiteManager.

4.4.2 Background on Traffic Safety Asset and HazMat Management

The following two sections provides a general review of some types of data collected in (1) evaluating traffic safety assets, and (2) management of HazMat on site.

4.4.2.1 Data Needs for Traffic Safety Asset Management

All three DOTs have a dedicated operations division that tracks the condition of traffic safety assets throughout their states. Guardrails, pavement markings, roadway lighting, traffic signals, and traffic sign structures are some examples of traffic safety assets (WSDOT 2018; RIDOT 2018; LADTOD 2018). Analysis of each state's asset management plan, a federal requirement under the 2012 Moving Ahead for Progress in the 21st Century act (MAP-21), found that inspection data collected during the

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construction phase is not integrated into the asset management program (Yuan et al. 2017; WSDOT 2018; RIDOT 2018; LADTOD 2018). Maintenance personnel are tasked to collect information that identifies, locates, and inspects the conditions of their assets during the operations phase of projects. WSDOT and LADOTD use maintenance management database systems to track asset information. WSDOT uses their internally developed Highway Asset Tracking System (HATS) to collect and manage asset data sets (WSDOT 2018). LADOTD uses a maintenance management system developed by AgileAssets, Inc. The workflow involved for WSDOT and LADOTD in capturing asset conditions into their database system are similar. A maintenance inspector travels onsite to record the date of assessment, asset type, location, and notes and photos of its condition. This is generally done using a mobile device (WSDOT 2018; LADOTD 2018).

RIDOT currently does not use any maintenance management system to track its traffic safety assets (RIDOT 2018). A series of manual inventory tracking tasks were conducted between 2014 and 2015 to collect information on the location of guardrails and safety sign locations and their condition. All other traffic safety assets are evaluated based on the time they were installed and rehabilitated or replaced according to their design life (RIDOT 2018). For traffic safety assets, maintenance inspectors generally collect the date of assessment, asset type, location, and asset condition information for asset inventory activities (RIDOT 2018).

Data collected during the construction inspection phase such as asset material classification, location of installment, narratives and photos of the installation process, and other decisions made affecting the initial quality or condition of the assets can potentially minimize the data collection effort involved in asset management activities.

4.4.2.2 Data Needs for HazMat Management

WSDOT, RIDOT, and LADOTD have project requirements during the construction phase that require the collection of environmental compliance data. The standard specifications of the three DOTs state that environmental compliance personnel are required to identify, report, and manage any incidents involving the handling and disposal of HazMat. Examples of incidents include encountering of unknown HazMat onsite (i.e., discovery of underground storage tanks), finding releases of unknown Hazmat, and spills from construction activities and the traveling public (WSDOT 2018; RIDOT 2004; LADOTD 2016).

Contractors are required to comply with environmental compliance plans and regulations established during the design and pre-construction phase. Projects managed by all three DOTs work with other

regulatory agencies that oversee environmental compliance requirements (e.g., federal entities, department of environmental management, dedicated environmental divisions within DOT, etc.) (WSDOT 2018; RIDOT 2004; LADOTD 2016; WSDOT 2018; LADOTD 2017; RIDEM 2015). For all three DOTs, the project inspector, and depending on the scope of the project and DOT organizational structure, other environmental DOT divisions, collect and manage environmental compliance data and report noncompliance activities to appropriate regulatory agencies (WSDOT 2018; RIDOT 2004; LADOTD 2016; WSDOT 2018; LADOTD 2017; RIDEM 2015). The environmental compliance requirements for the three DOTs are specified and monitored by designated divisions or agencies separate from the construction divisions. WSDOT and LADOTD have dedicated environmental agency offices (WSDOT 2018; LADOTD 2017). RIDOT coordinates environmental compliance data with the Rhode Island Department of Environmental Management (RIDEM 2015).

In summary, the timely accessibility of HazMat data collected by the DOT project inspectors using inspection database systems, such as HeadLight, can benefit environmental regulatory agencies that typically do not have access to this type of information. Being able to access and search through observational data (i.e. photos of incident and management methods, time and location of occurrence, etc.) in one central system, rather than through multiple forms and reports stored in different repositories, can provide personnel responsible for environmental compliance a better understanding of what transpired onsite.

4.5 Methods

The following sections provide the data collection process and the descriptive statistic measures used to describe the HeadLight dataset collected by WSDOT, RIDOT, and LADOTD. This section also provides the method used to process and extract HeadLight data so that it can be used for traffic safety asset and HazMat management activities.

4.5.1 Data Collection

Inspection data collected in the HeadLight system from 11 projects are included in this study (Table 4-1). The projects were selected based on the accessibility of HeadLight data at the time of the research (i.e., WSDOT only had four projects using HeadLight during the study period). Projects were also selected to include a variety of project types and sizes to the extent possible. Research participants included in this study are comprised of any personnel involved in the collection of observation data using the HeadLight

system. A total of 112 personnel collected data using HeadLight across all DOTs. Table 4-2 presents the breakdown of personnel roles by state and project.

Table-4-1. DOT Projects Included in this Study

Agency	Contract Number	Project Name	Cost (dollars)	HeadLight Usage (months)
WSDOT	8549	Alaskan Way Viaduct – Replacement North Access Connection	$41,640,622	37
	8607	I-5 M St to Portland Ave - HOV	$98,175,433	32
	8625	SR 520 Montlake to Evergreen Pt. Bridge West Approach Bridge North	$199,537,370	40
	8670	I-5 Portland Avenue to Port of Tacoma Road – Northbound HOV	$134,709,929	41
RIDOT	2016-CB-038	I-195 Relocation – Contract 16 – Providence River Pedestrian Bridge	$16,971,058	4
	2017-CB-046	Pine Street Bridge No. 548 (31)	$6,488,426	4
	2016-CH-054	US Route 6 (Hartford Ave), C-1	$5,893,815	4
LADOTD	H.012193.6	I-20: EB Entrance Ramp at LA 169 (Precast Concrete Pavement)	$2,873,512	9
	H.011111.6	I-49N, Segment K – Phase 2 (I-220 to MLK Drive)	$137,794,876	10
	H.009012.6	LA 10 & LA 67 Intersection Widening	$1,230,523	10
	H.011224.6	US 190: Guardrail/Rutting Rep. (Phase 1)	$7,698,435	9

Table 4-2. Personnel Roles by State and Project

Agency	Contract Number	Role Title	Number of Personnel
WSDOT	8549	Project Inspector/Engineering Technician	8
		Materials Technician	1
	8607	Project Inspector/Engineering Technician	20
		Assistant Inspector	8
		Records Assistant	1
	8625	Project Inspector/Engineering Technician	20
		Intern	3
		Environmental Engineer	1
		Risk Analyst	1
		Project Manager	1
		Materials Technician	1
		Change Order Engineer	1
		Project Engineer	1
	8670	Project Inspector/Engineering Technician	15
RIDOT	2016-CB-038	Project Inspector/Engineering Technician	3
		Intern	2
		Resident Engineer	1

59

	2017-CB-046	Project Inspector/Engineering Technician	3
		Resident Engineer	2
	2016-CH-054	Project Inspector/Engineering Technician	1
LADOTD	H.012193.6	Project Inspector/Engineering Technician	3
	H.011111.6	Project Inspector/Engineering Technician	7
		Assistant Project Engineer	1
	H.009012.6	Project Inspector/Engineering Technician	3
		Materials Engineer	1
		Office Manager	1
	H.011224.6	Project Inspector/Engineering Technician	2

HeadLight data collected up to August 23, 2018 are included for analysis. Each data collected in HeadLight, or observation, contains 16 unique data field associations. The "state" and "project" data fields were added by the research team to associate every observation with the appropriate DOT and project. Table 4-3 categories the data fields and provides data entry examples from a WSDOT project. The *entry type* column describes whether the data field is populated automatically (i.e., from mobile device sensors, HeadLight system) or manually inputted by the HeadLight user. If the user does not complete any manual data fields, the data field will be empty.

Table 4-3. Data Collected for Each Observation

Data Field	Entry Type	Example Entry
State	N/A[a]	WSDOT
Project	N/A[a]	8549 - Alaskan Way Viaduct – Replacement North Access Connection
Name	Automatic/ Manual[b]	KLB Grading
Description	Manual	Grading the area between the A-Line and Wall 6.
Link	Automatic	https://fieldbook.headlight.paviasystems.com/#/project/57/journal/grid/observation/542182
Type	Automatic	Image
Time	Automatic	11/18/2015 8:25
Created By	Automatic	John Doe
Latitude	Automatic[c]	47.6243
Longitude	Automatic[c]	-122.344
Station	Manual	LE 1300+52
Offset	Manual	R 16'
Contractor	Manual	KLB
Equipment	Manual	CAT 140H Motor Grader
Pay Item	Manual	030 Roadway Excavation Including Haul
Tag	Manual	Work activity summary

Notes:
a. Fields entered in by the research team to associate observation to DOT and project.
b. A default name is automatically given to every observation. Users can manually change the observation name.

c. Latitude and longitude values are automatically obtained when the mobile device is connected to a GPS signal and the GPS tracking feature is turned on. No location coordinates are recorded if the mobile device is not connected to a GPS signal or if the GPS tracking feature is turned off.

4.5.2 Descriptive Statistic Measures

The following metrics were chosen to evaluate the general HeadLight dataset used in this study:

- **Data volume**: the overall quantity of the observations regardless of form
- **Data variety**: number of observation types (e.g., narrative, photo, video)
- **Average number of observation types collected per day per person for each project**: description of the average volume and variety of inspection data collected per person broken down by state and project. This measure is included to show how the average personnel on a project used HeadLight on a daily basis.
- **Data completeness**: percentage of data fields (Table 4-3) with data (vs. null fields)

The above metrics were chosen to provide a general understanding on how the HeadLight system was used by each DOT and describes the quality of the dataset available for potential application analysis.

4.5.3 Application of Data for Traffic Safety Asset and HazMat Management Activities

To demonstrate the use of the construction inspection data in HeadLight for traffic safety asset and HazMat management purposes, the entire HeadLight dataset is imported to the Tableau data analysis and visualization software. Tableau enables analysis, such as custom search queries, for any data field associated to HeadLight observations. The following section discusses the approach taken to extract relevant HeadLight data for these two activities.

4.5.3.1 Traffic Safety Asset Management

To investigate potential applications of the HeadLight dataset for asset management use, the study first identified typical data captured by maintenance inspectors. A review of each state's Transportation Asset Management Plan, discussed previously in the backgrounds section, found that maintenance inspectors collect asset condition data which includes the type of asset, location of installment, and observations and visuals rating the asset's conditions. The review also found that construction inspection data that can support the asset management data needs are not directly accessible to DOT maintenance offices. To provide an example of how construction inspection data can benefit traffic safety asset management data needs, this part of the study extracts construction inspection observations related to guardrails by searching for key guardrail terms in the description and pay item

61

data fields. Search terms used include "guardrail" and "railing". After obtaining the search results, observations describing the sequence of construction processes for specific guardrail installation activities are compiled together. Observation data presented to describe the guardrail construction process include type, time, latitude, longitude, description, and pay item data fields. Pay items have been included in the analysis as they typically provide information on the type and classification of materials installed onsite.

4.5.3.2 HazMat Management

A review of each state's standard specifications and other environmental guidelines, described previously in the background section, found that multiple personnel (project inspectors, environmental compliance inspectors, and other non-DOT environmental regulation personnel) are monitoring and collecting similar environmental compliance activities onsite as this information is not stored in a way that can be efficiently shared with all parties involved. To demonstrate the value of collecting and storing structured data using cloud computing technology, all HazMat related HeadLight observations are extracted. Terms related to HazMat activities are searched through the description and name data fields. Search terms include "environmental", "hazmat", "spill", and "leak". Search results are analyzed to remove observations unrelated to HazMat management. Data presented to describe HazMat management activities include type, time, latitude, longitude, and description.

4.6 Results

This section presents the results of the descriptive statistic measures and the applications of the HeadLight data for traffic safety asset and HazMat management activities.

4.6.1Descriptive Statistics of the HeadLight Dataset

Table 4-4 presents the overall volume of the observations collected in the HeadLight system and breaks down the number of different observation types collected throughout the data examination period. Figure 4-1 further breaks down the quantity of each type of observations collected by each DOT. Note that LADOTD and RIDOT use a quantity scale that is different than the scale used for WSDOT. Figure 4-2 displays the average number of observation types collected for each project. Table 4-5 shows the percentage of data fields with complete data.

Table 4-4. Quantity of Observations in the HeadLight Dataset

Observation Type	Description of Observation Type	Quantity of Observations
Image	Photograph	82,090
Narrative	Free form narrative field	57,918
Weather	Temperature, weather condition, precipitation, windspeed, and humidity	23,528
Start/Stop Work	Start time, stop time, and duration of any activity	13,063
Traffic Control	Yes/no fields for traffic control labor requirements, work zone traffic control plan approval, and monitoring of current flagging card/certification	5,662
Videos	Captures of video recording	437
Materials	Calculation feature enabling calculation of material quantities	191
Density Measurements	Percent compaction density measurement of materials	120
File	Attachment of any file format	32
Temperature	Recording of temperature of construction materials	19
Audio	Capture of audio recording	7
GRAND TOTAL		**183,067**
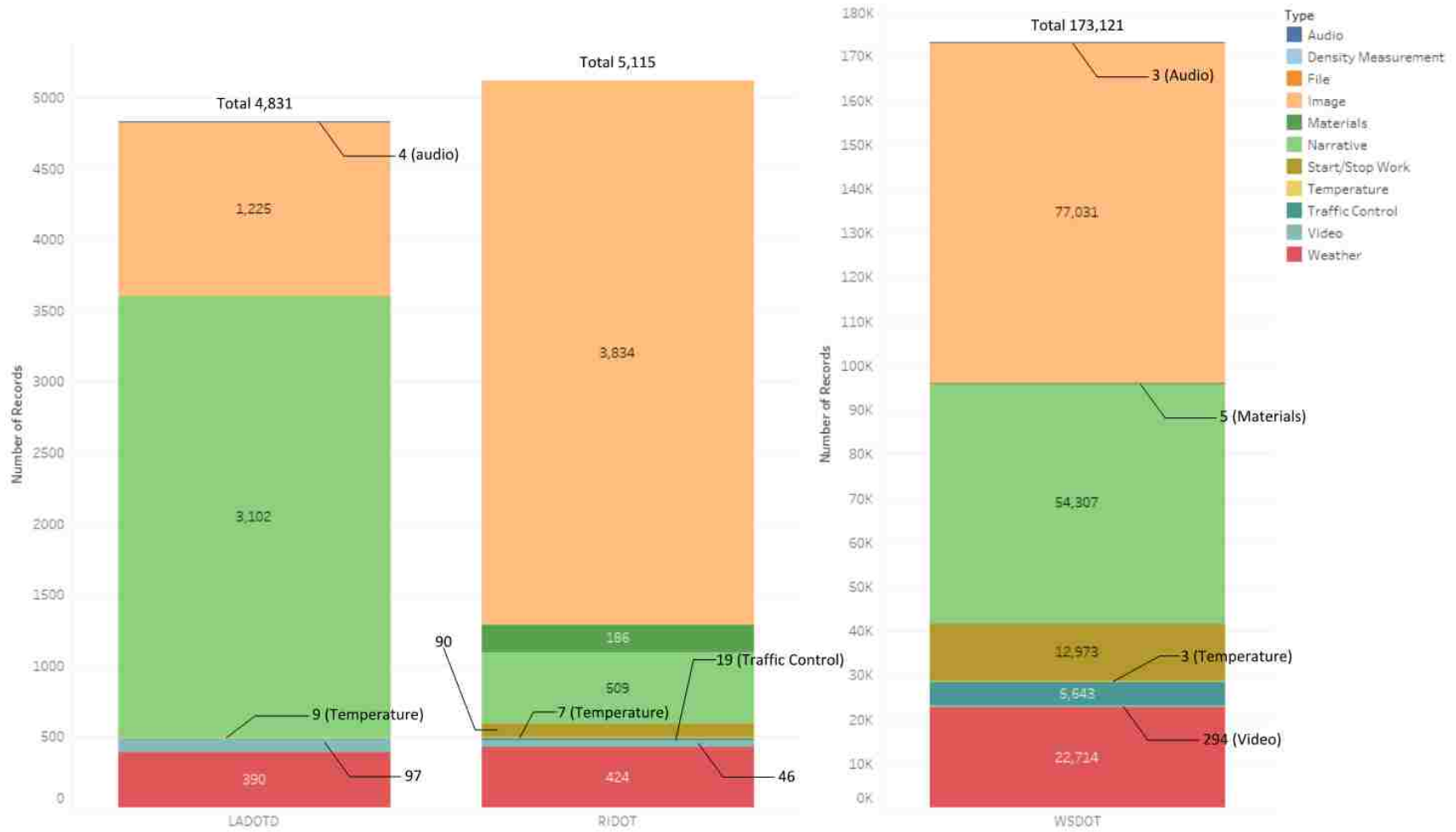
Figure 4-1. Quantity of observation collected by DOTs by Type.
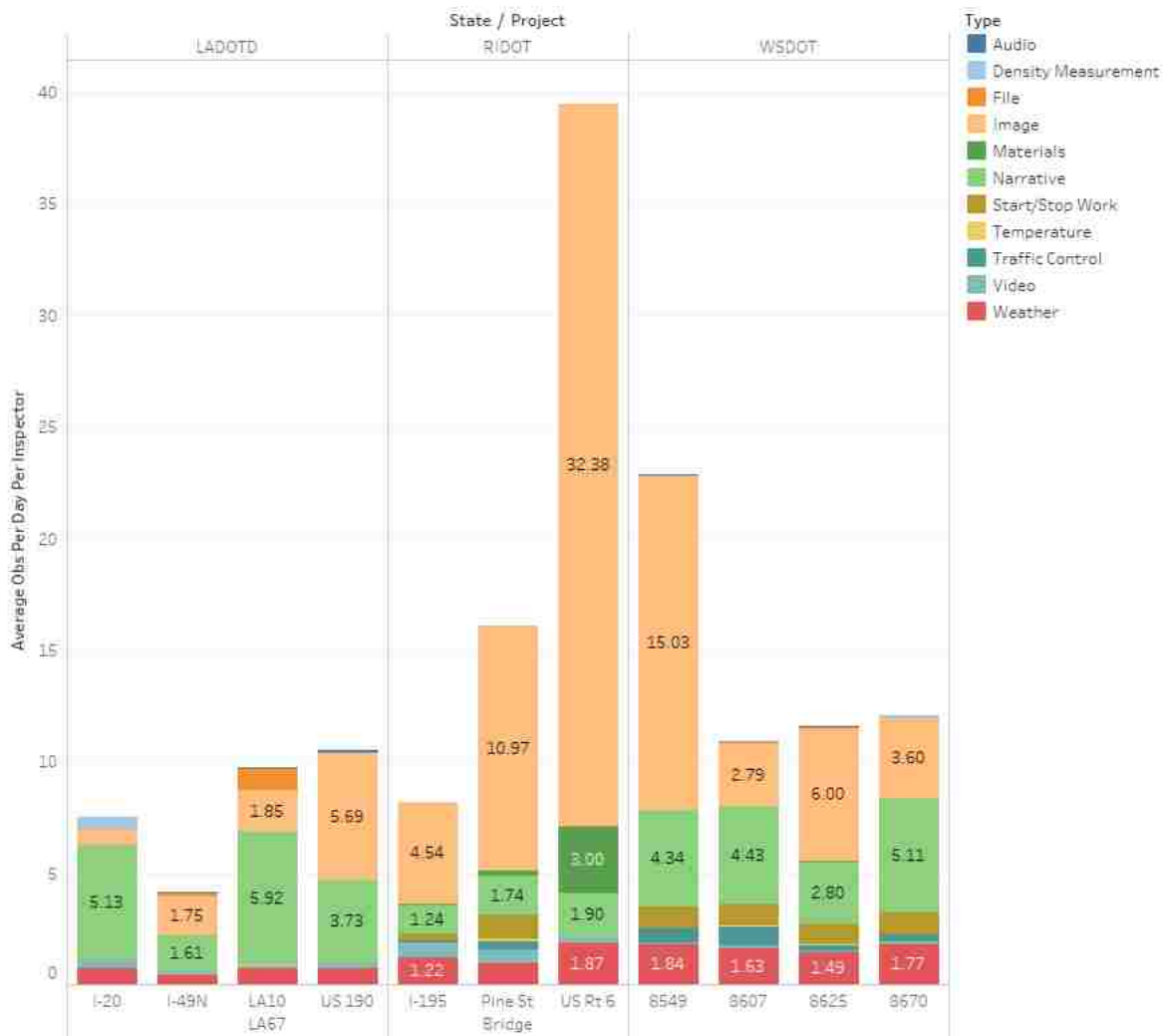
Figure 4-2. Average number of observations collected per day per person.

Table 4-5. Percentage of Data Fields with Complete Data

Data Field	System-Wide		Percentage of Complete Fields (%)			
	Number of Complete Fields	Number of Incomplete Fields	System-Wide	WSDOT	RIDOT	LADOTD
State	183,067	0	100.00	100.00	100.00	100.00
Project	183,067	0	100.00	100.00	100.00	100.00
Name	182,571	496	99.73	99.73	99.57	99.90
Description	117,214	65,853	64.03	64.67	26.53	80.65
Link	183,067	0	100.00	100.00	100.00	100.00
Type	183,067	0	100.00	100.00	100.00	100.00
Time	183,067	0	100.00	100.00	100.00	100.00
Created By	183,067	0	100.00	100.00	100.00	100.00
Latitude	180,841	2226	98.78	98.76	99.78	98.45
Longitude	180,841	2226	98.78	98.76	99.78	98.45
Station	1,080	181,987	0.59	0.19	0.27	9.50
Offset	825	182,242	0.45	0.09	0.04	7.43
Contractor	104,875	78,192	57.29	57.95	61.19	29.43
Equipment	41	183,026	0.02	0.00	0.00	0.85
Pay Item	78,765	104,302	43.03	43.82	42.89	14.51
Tag	87,236	95,831	47.65	47.83	10.71	80.54

4.6.2 Potential Application of the Headlight Data

Figure 4-3 presents an example showing how HeadLight data was imported into the Tableau visualization software. Each point on the map, color-coded to distinguish observation types, represents one HeadLight observation. Additional data field search parameters were included and used to search through the HeadLight data for relevant information described in the following sections. Figure 4-4 shows an example of extracting observations related to testing of permanent ground anchors of a wall on WSDOT's 8625 project. Similar processes were used to search for HeadLight data that can be applied to traffic safety asset management and HazMat management activities. The following sections describe this process in more detail.
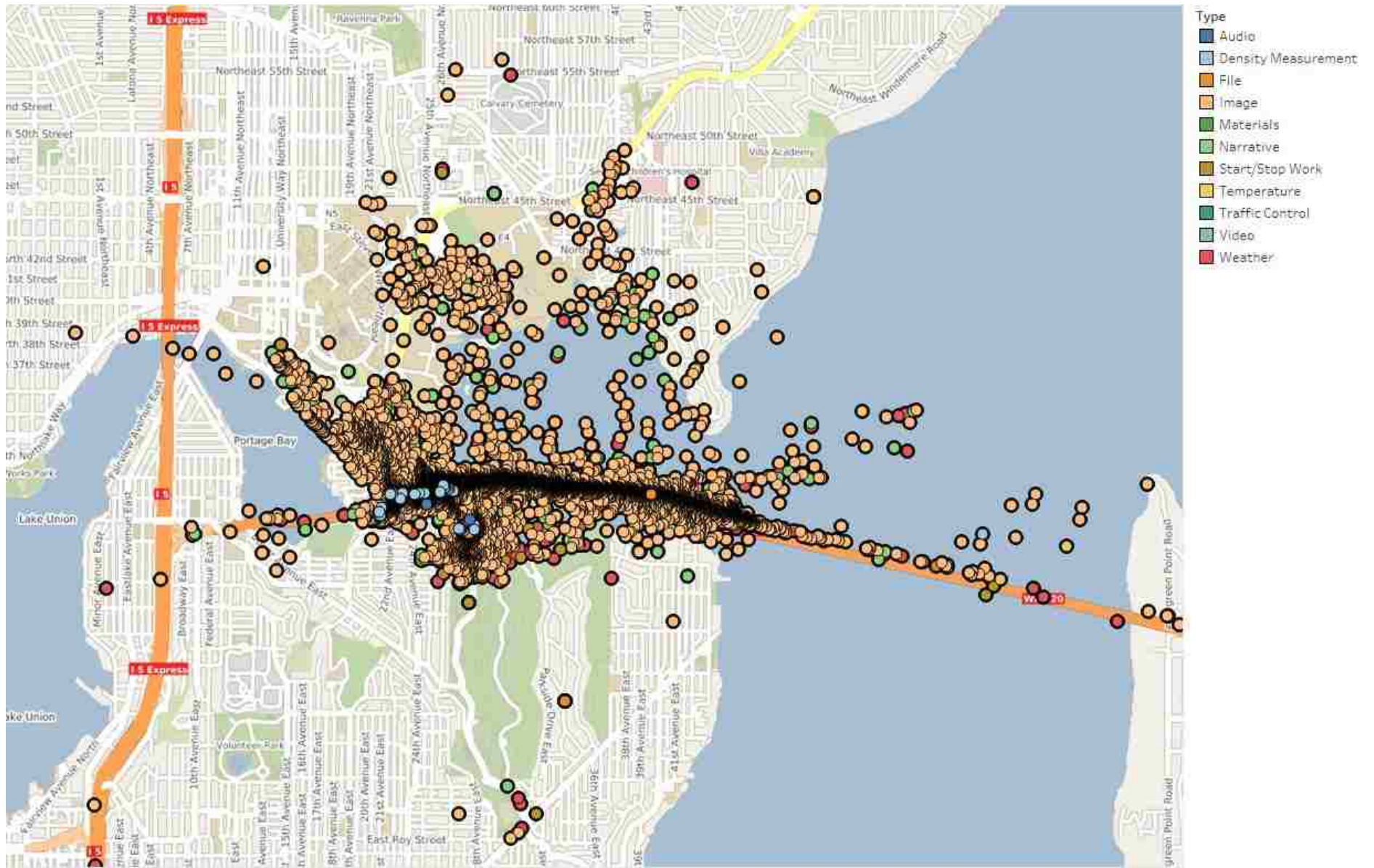
Figure 4-3. Map showing the locations of observations collected for WSDOT project 8625.
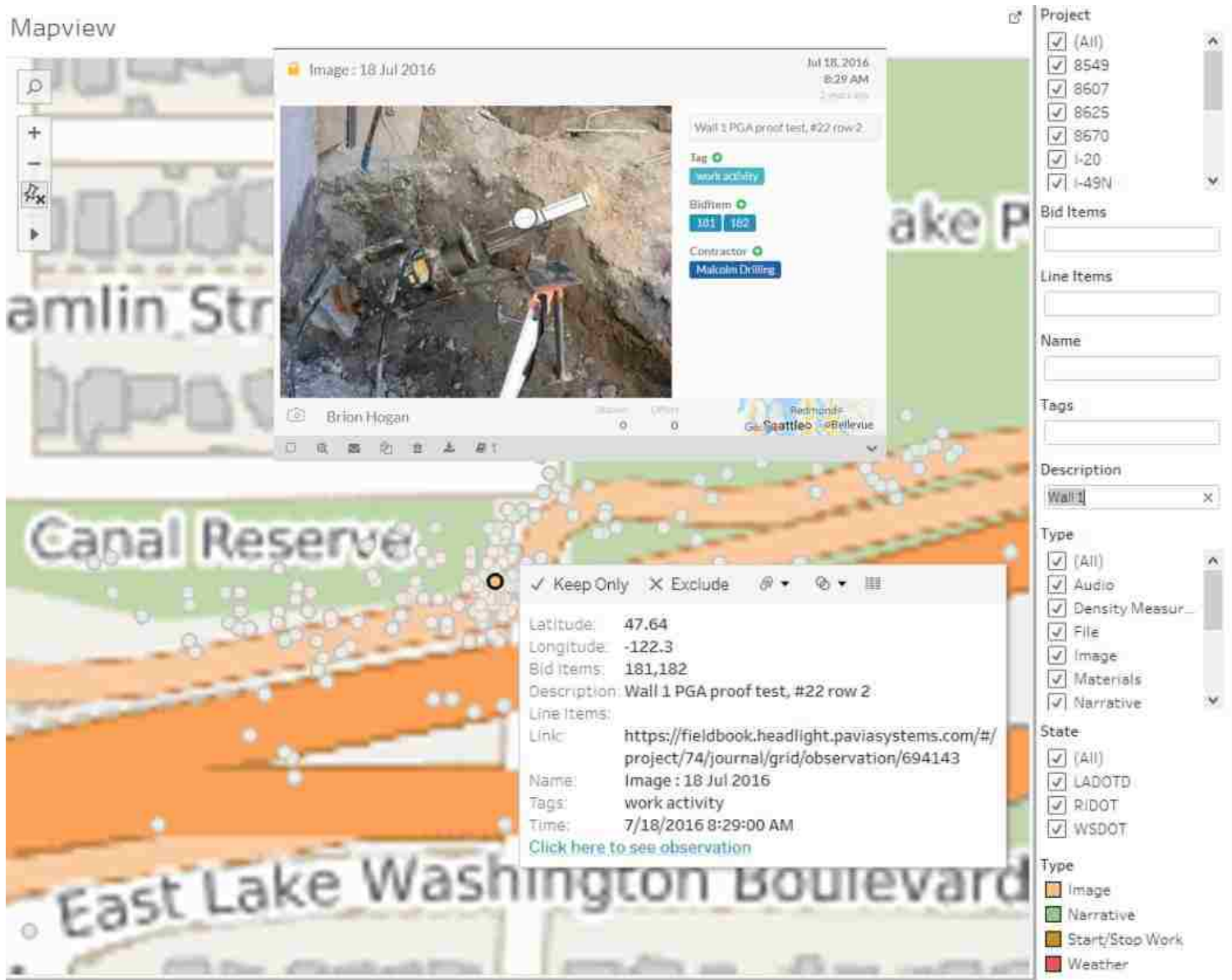
Figure 4-4. Example of using the search queries to find observations related to "Wall 1".

69

4.6.2.1 Traffic Safety Asset Management Application

Table 4-6 shows the number of releveant observations found related to the construction inspection of guardrails. From the observations obtained from the search query, observations that provide information of the construction process of a specific guardrail activity were extracted. Table 4-7 and 4-8 present a sequence of guardrail construction activities from WSDOT's 8607 project and RIDOT's 2016-CB-038 project. The search result did not yield any comprehensive construction sequence of guardrail construction for any LADOTD project. For that reason, the results in this section do not present any data from any LADOTD project.
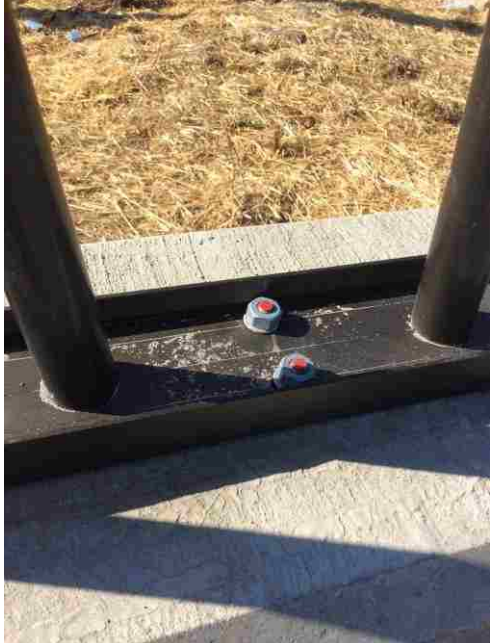
Table 4-6. Search Results for Observations Related to Guardrails

Search Term	Data Field	WSDOT	RIDOT	LADOTD	DOT Total
Guardrail	Description	335	0	2	337
Railing	Description	715	16	0	731
Guardrail	Pay Item	32	15	0	47
Railing	Pay Item	51	32	0	83

Observation Type	Date and Time	Latitude and Longitude	Description	Pay Items
	9/28/2016 10:59 AM	47.232 -122.435	Bridge railing to be used for the western pedestrian barrier of Bridge 5/444 is an approved material per QPL-0218 with an Approved Shipment Tag No. S001836.	117: Bridge Railing Type BP
Narrative	9/28/2016 3:10 PM	47.232 -122.435	Contractor brought to my attention that the balusters of the BP rails on the western approach slab pedestrian barrier of Bridge 5/444 are out of plumb by approximately 1/4". Contractor was approved to install the BP rails given they are aesthetically pleasing per Standard Specification 6-06.3(2).	117: Bridge Railing Type BP

	09/29/2016 10:29 AM	47.234 -122.434	Contractor has begun drilling anchor bolt holes for BP railing on the west pedestrian barrier of Bridge 5/444.	117: Bridge Railing Type BP
	09/29/2016 11:01 AM	47.233 -122.434	Contractor is continuing to drill the holes for the anchor bolts of the BP railing for Bridge 5/444 on the western pedestrian barrier. Holes are a minimum of 5" deep.	117: Bridge Railing Type BP

Narrative	9/30/2016 11:19 AM	47.233 -122.434	Bridge rail hardware to be used on the western pedestrian barrier BP rail of Bridge 5/444 has been verified to be an approved material per MFR-0221. Epoxy to be used on the western pedestrian barrier BP rail of Bridge 5/444 has been visually verified to be an approved material per QPL-0221. Contractor has completed the drilling of anchor bolt holes from western pedestrian barrier at the Pier 1 approach slab to approximately PAC-Line STA 17+75.	117: Bridge Railing Type BP
	09/30/2016 1:52 PM	47.234 -122.434	The picture shows the typical finished hardware installation of the resin bonded anchor system for the bridge railing for Bridge 5/444. Once the holes are drilled to the proper embedment depth (5" minimum) threaded anchor bolts are inserted with the approved epoxy resin. The rail can then be attached using the approved nuts and washers.	117: Bridge Railing Type BP

	09/30/2016 1:52 PM	47.234 -122.434	This photo shows the bridge railing that has been installed at the northern end of the western pedestrian barrier of Bridge 5/444.	117: Bridge Railing Type BP
	10/03/2016 10:46 AM	47.233 -122.434	Crew has begun installing BP rail along bridge 5/444 right barrier. [Name of personnel], foreman, has informed me that they have previously discussed with [name of inspector], WSDOT inspector, about placement of BP rail along the right barrier to be placed 1/2" offset towards the outside edge for better visual appeal. Shown in picture is the minor offset. Crew intends to secure all BP rails that do not have a skew in them. The skewed pieces are on order currently. Once all pieces are secured with anchor bolts, and placement has been verified with me, they will come back through and epoxy the anchor bolts in place. Epoxy being used is Adhesives Technology UltraBond HS-200 anchoring epoxy, visually verified and conforming to current approved QPL-0221. Anchor rods, nuts, and washers have been	117: Bridge Railing Type BP

74
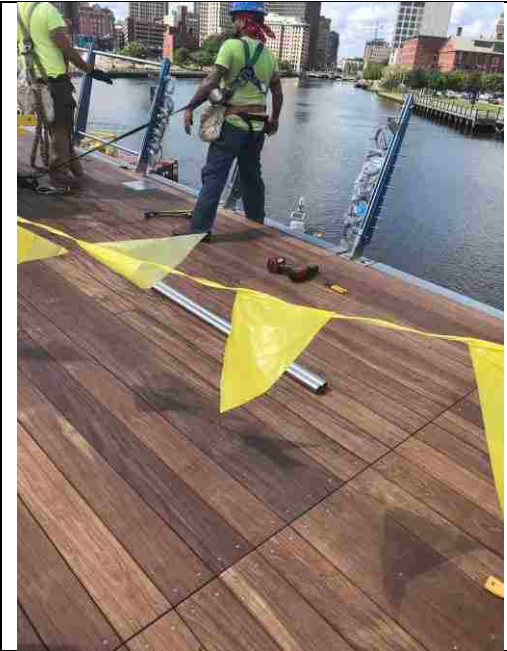
			approved via QPL-022D, and accepted via cert MFR-0221.	
Narrative	10/3/2016 2:13 PM	47.233 -122.434	I have measured the drilled holes on the right sidewalk on bridge 5/444 BP rail for embedment depth and have confirmed 5" depth in conformance to plan sheet PA97 for 3/8" diameter resin bonded anchors. Crew begins applying epoxy for end holes on each section. Remaining holes will be epoxied tomorrow as Crew moves forward on the embedment drilling.	117: Bridge Railing Type BP
	10/04/2016 2:37 PM	47.233 -122.434	Crew has installed approximately 88 LF of BP rail today thus far. Embedment depths have been verified at 5", and are in conformance with plan sheet PA97. All rail above live traffic is epoxied in place, and the remaining rails are secured with hardware only until weather allows the drilled holes to be cleaned properly, in order to apply epoxy per manufacturers recommendations.	117: Bridge Railing Type BP
	11/4/2016 10:35 AM	47.234 -122.434	Photo shows Contractor beginning to install custom cut sections for bridge BP railings at Bridge 5/444, beginning at Pier 1 and progressing ahead on stationing.	117: Bridge Railing Type BP

Observation Type	Date and Time	Latitude & Longitude	Description	Pay Item
	07/26/2018 7:41 AM	41.821 -71.405	Another angle of the tube railing seat removal	
	07/26/2018 7:46 AM	41.821 -71.408	Laborer foreman notching an end piece from deck tube railing seat	
	07/26/2018 10:58AM	41.820 -71.405	Cutoff from deck tube railing base	

76

	07/27/2018 5:27 AM	41.820 -71.406	Architectural railing	123.0002: Architectural railing, Type D, West Abutment W/LED (LF)
	07/27/2018 5:28 AM	41.820, -71.406	Delivered architectural railing Type D at the west end	123.0002: Architectural railing, Type D, West Abutment W/LED (LF)
	08/14/2018 5:29 AM	41.820 -71.406	[Contractor] crew seeing on the edge of the north side of the bridge; they are preparing for installation of the architectural railing, type A	120.0002: Architectural railing, Type A, upper deck W/LED (LF)

77

	08/14/2018 7:10 AM	41.820 -71.406	Rust forming on the head of the bolt that hold the post base in place on the bridge	120.0002: Architectural railing, Type A, upper deck W/LED (LF)
	08/15/2018 5:23 AM	41.820 -71.406	They are installing the railing on the northern side of the bridge	120.0002: Architectural railing, Type A, upper deck W/LED (LF)

	08/15/2018 11:39 AM	41.820 -71.405	[Contractor] installing rail on bridge	120.0002: Architectural railing, Type A, upper deck W/LED (LF)
	8/16/2018 10:12 AM	41.820 -71.406		120.0002: Architectural railing, Type A, upper deck W/LED (LF)

79

4.6.2.2 Environmental Compliance Application
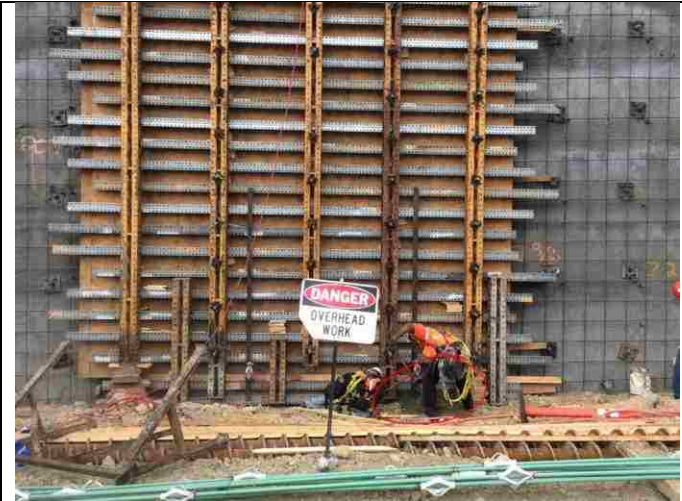
Table 4-9 shows the number of releveant observations found related to the handeling and disposal of HazMat. RIDOT and LADOTD did not captured many observations related to the search term used to query HazMat related observations. Demonstration of construction inspection data use for reviewing HazMat related activities presents HeadLight data from WSDOT only. Table 4-10 displays HazMat data collected collected on WSDOT's 8607 project.

Table 4-9. Search Results for Observations Related to HazMat Management

Search Term	Data Field	WSDOT	RIDOT	LADOTD	All DOTs
Environmental	Description	286	0	3	289
hazmat	Description	9	0	0	9
spill	Description	326	0	0	326
leak	Description	444	1	1	446
Environmental	Name	160	0	0	160
hazmat	Name	0	0	0	0
spill	Name	28	0	0	28
leak	Name	34	0	0	34
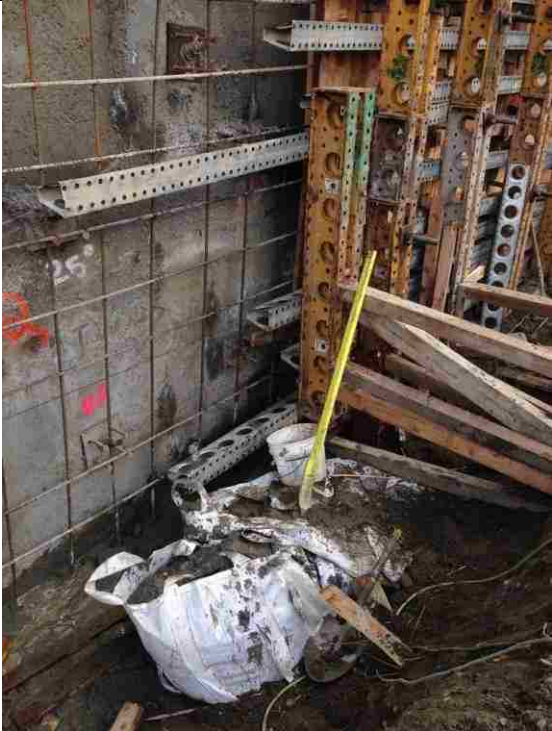
80

Observation Type	Date and Time	Latitude & Longitude	Description
	5/7/2015 4:08 AM	47.230 -122.447	Pic - Facing Southwest // hydraulic hose busted loose on the placer. [Contractor] crew gathered the spill kit and deployed all resources to clean up. [Contractor] foreman stated that he will try and repair the hose and finish paving with the 4 trucks onsite. All fluid is contained atop the HMA base.
	6/12/2015 11:16 AM	47.234 -122.429	As I was driving the project site, I noticed what appears to be dried up concrete slurry in the gutter line of the left shoulder of the SNB line, east of the pier 6 work area. I have called [name of personnel] to clean the area up and sent him a picture because he is not answering his phone. It appears someone dumped concrete slurry in the ditch line, which spilled into the gutter line. It is currently dry outside, so it is unknown when this violation occurred, how much was drained, and what the white substance is. I have notified [name of personnel], field engineer of the matter.

81

	6/19/2015 7:56 AM	47.232 -122.436	Photo shows concrete spilling out of form for panel section 15+75 to 15+90, an indication that proper blocking was not achieved in this location.
	6/20/2015 2:18 PM	47.233 -122.430	Image is at pier 6 and appears to be [contractor's] dumping site for their concrete. I've addressed this with [name of personnel] as not being acceptable. [Contractor] has Eco Pans onsite to use, and appears that they are using them, then dumping the hardened concrete into this pile. The pile needs to be removed, and [contractor] needs to be disposing of fresh concrete offsite, per their spill prevention plan. This will be addressed with [name of personnel], the site spill prevention contact.

82

	09/18/2015 2:18 PM	47.055 -122.794	[Supplier] concrete truck #213 has blow the drum hydraulic line. Crew is implementing the spill plan and is attempting to contain spill site. Truck will not be able to place its load.
	9/18/2015 9:53 PM	47.232 -122.434	Crew has begun to sweep roadway by making multiple passes over spill area with water jets and rotary sweepers.

	9/18/2015 9:55 PM	47.232 -122.434	Crew has begun to apply degreaser to spill area.
	9/18/2015 10:15 PM	47.232 -122.434	Crew has finished cleaning spilled area.

	10/14/2015 11:36 AM	47.233 -122.435	While placing first lift of concrete at random board panel section 21+30 to 21+50, left side of form has blown out due to inadequate blocking. Contractor has contained spilled concrete into bags shown in photo, while other crew members are continuing to re-block the left side.
	1/7/2016 1:30 PM	47.233 -122.431	Crews cleaning up transmission fluid spill.

	3/1/2016 11:18 AM	47.233 -122.434	Crew is enacting spill procedure in an attempt to clean spill.
	7/14/2016 10:35 AM	47.233 -122.435	Concrete truck spilled hydraulic fluid. [Contractor] activated their spill plan.

	8/19/2016 3:17 PM	47.231 -122.444	Caterpillar TH83 611 spill clean up
	8/25/2016 8:17 AM	47.234 -122.434	Spill on deck overhang at mid span 2.

	9/14/2016 12:26 PM	47.233 -122.429	Diesel spill.
	9/14/2016 12:26 PM	47.233 -122.430	Hydraulic spill.

	9/14/2016 12:29 PM	47.233 -122.430	Hydraulic spill.
	9/15/2016 3:00 PM	47.242 -122.341	Diesel spill cleanup.

	11/4/2016 3:07 PM	47.234 -122.427	Concrete slurry spill on E D St.
	11/4/2016 3:07 PM	47.234 -122.427	Concrete slurry spill on E D St.

	2/8/2017 1:26 PM	47.235 -122.427	It was found that [supplier] truck #8 of today's pour was leaking hydraulic fluid. Contractor placed a piece of plastic below the truck and began soaking up the hydraulic fluid with diapers.
	2/15/2017 3:56 PM	47.232 -122.432	[City owned] dump truck spilled dirt on roadway.

	2/15/2017 3:56 PM	47.232 -122.432	[City owned] dump truck spilled dirt on roadway.
	5/8/2018 2:52 PM	47.234 -122.427	While placing concrete into the hopper/tremie from the bucket for Column 3B, the bucket was not closed enough and the hopper was overfilled curing concrete to spill down onto the Laborer vibrating below as well as the base of the Column. Laborer Foreman is cleaning up the spilt concrete.

92

	10/11/2018 11:20 PM	47.231 -122.442	I5SB shoulder south of Delin, sand placed on oil spill left behind by damaged vehicle

4.7 Discussion

The following sections provide discussions on descriptive statistics measures and the application of the HeadLight data for traffic safety asset and HazMat management purposes.

4.7.1Descriptive Statistics of the General HeadLight Dataset

Examination of the descriptive statistic measures of the general HeadLight datasets revealed the following findings:

- **Image observations account for nearly half of the observations collected in HeadLight.** Table 4-4 shows that image observations were widely used by the three DOTs. Although Figure 4-1 shows variability in the amount of image observations collected by each state (44%, 75%, and 25% of total observations for WSDOT, RIDOT, and LADOTD respectively), the amount of image and narrative observations collected by these DOTs present less variability (76%, 85%, and 90% of total observations for WSDOT, RIDOT, and LADOTD respectively). DOTs using HeadLight communicated events that transpired onsite mainly through photographs and narratives.

- **DOTs used HeadLight in different ways.** Figure 4-1 indicates variability in the way HeadLight was used by the DOTs. The distribution of observation types collected varied widely between the DOTS. For example, LADOTD heavily favored the use of narrative observations, which accounted for over 60 percent of total observations collected. Out of the three DOTs, LADTOD collected the least amount of photo observations, which accounted for 25 percent of total observation collecting. The integration of HeadLight to LADTOD's SiteManager system may have influenced the types of observations collected by the inspectors. Inspectors were required to create a series of narrative observations each day in HeadLight to populate data fields in SiteManager (e.g., general remarks and traffic control). Due to these integration process requirements, inspectors may have opted to use narratives to collect a wide range of observations rather than using other HeadLight observations developed to capture those specific activities (e.g., "narrative" observations used instead of "traffic control" observation to record traffic control observations). Integration process requirements may have also limited the inspector's use of HeadLight by focusing only on the collection of information needed to populate fields in SiteManager. RIDOT heavily favored the collection of photo observations which accounted for 75 percent of total observations. WSDOT collected about the same portion of photo to narrative observations, which account for 44 percent and 31 percent of the total observations collected respectively. Compared to other DOTs, WSDOT recorded more start/stop

94

and traffic control observations. For all three DOTs, video, materials, density, file, temperature, and audio observation types accounted for less than 1 percent of the total observations. HeadLight was not directly integrated into any materials or quality tracking databases which may explain the small number of materials related observations collected in HeadLight. Inspectors likely collected materials related data using traditional forms or database systems.

- **Projects within a DOT used HeadLight in different ways.** Figure 4-2 shows variability in the distribution of the volume, and in some cases variety, of observations between projects. For example, inspectors working on WSDOT project 8549 recorded more photos (65 percent of the total observations) compared to the other three WSDOT projects. Although the amount of observation types collected varied throughout these projects, the projects mainly collected the same variety of observation types on a daily basis (on average, all four WSDOT projects collected photo, narrative, start/stop, traffic control, and weather observations each day). Similarly, the distribution of the amount and types of observations collected by RIDOT and LADTOD projects varied widely. This data suggests that the use of HeadLight varied between individual users, not just at the state and project level.

- **There are variations in the completeness of manual-entry data fields.** Out of all the manual-entry data fields, the description, contractor, pay item, and tag fields were found to be the most complete (40 to 60 percent complete). DOTs may have found value in associating these data fields with observations, which allow users to efficiently search for information through these data fields (e.g., retrieve all observations tagged with a specific contractor).

Although Figures 4-1 and 4-2 show data from multiple DOTs and projects, caution should be exercised when comparing results across states and projects. These figures show clear variations of the amount and types of observations collected and the results are dependent of the individuals using HeadLight. An inspector's use of HeadLight in capturing information can be a reflection of the project office's policy or guidelines, or interest in using a certain type of HeadLight observation over others. The capacity in which HeadLight was implemented also is a factor. Table 4-2 shows multiple personnel roles that used HeadLight to collect inspection data. The type and amount of observations collected by a resident engineer will differ from the types of observations collected by a materials engineer. These are all examples of factors that need to be consider when comparing HeadLight data across projects and states.

4.7.2 Potential Application of the HeadLight Dataset

4.7.2.1 Traffic Safety Asset Management Application

The observations describing the construction sequence of guardrail installations (Tables 4-7 and 4-8) identified the type of material used for the various guardrail components, the GPS locations of the guardrail, and various narratives and photos discussing the construction process and field decisions made onsite. For both examples, photos showing the condition of the guardrail at the time of installation were captured. Table 4-7 presents an image observation that contains a written description of field decision made to offset the original plan location of the bridge railing to achieve a better visual appeal. Observations also noted the exact type of epoxy, anchor rods, nuts, and washer and reference material certification documentation for each material. Table 4-8 contains an image observation that describe rust forming on bolt heads that secures the post base in place. This type of information is useful for asset management divisions in determining the cause of certain conditions observed during the operation phase of the project. Furthermore, the inspection observations displayed in Tables 4-7 and 4-8 provide maintenance personnel narratives and images of the construction sequence that was used to construct the asset.

Asset management divisions can benefit from having access to these detailed construction inspection observations. Project inspection personnel collecting data in HeadLight collect the similar types of data needed by asset management divisions. Agencies like WSDOT and LADOTD that use asset management database systems can benefit from integrating applicable observations and data fields into their system. Access to inspection observation data can minimize or eliminate the effort involved in maintenance personnel searching through project plans and as-builts to identify asset locations. Agencies like RIDOT, with limited personnel and technology resources, can benefit from having access to project inspection database systems where they can search for asset locations and other needed information, minimizing the need to travel onsite.

4.7.2.2 Environmental Compliance Application

A significant number of HazMat management activities found in the HeadLight system (Table 4-10) were comprised of image and narrative observations that recorded incidents of fuel and other HazMat spill incidents. The observations provided the date and time, the GPS location, and images and or narratives describing the incident. Several observations shown in Table 4-10 describe the HazMat incident and how the contractor and responsible parties followed spill containment and disposal plans to address the issue. These types of observations can help DOT divisions and other regulatory agencies responsible for

environmental compliance management identify and address environmental issues. Compared to the traditional process of gathering environmental compliance information through reviewing reports and conversations with personnel, responsible parties that have access to HeadLight can search and obtain large amounts of supporting data in a timely manner to assess and address environmental incidents that occur on projects.

4.8 Conclusions and Recommendations

This study provided descriptive statistics of the HeadLight data collected by WSDOT, RIDOT, and LADOTD and investigated the potential use of the inspection data to create value beyond project inspection purposes. The potential use of the HeadLight dataset focused on uses for traffic safety asset management and HazMat management activities. While the scope of the study was limited to these specific applications, similar application of the inspection dataset may apply to other DOT functions, offices (such as planning, design, and financial DOT divisions), and other stakeholders involved in the construction of transportation infrastructure projects. Conclusions based on this study include:

1. **Inspectors using HeadLight predominantly used photo and narrative observations to record and communicate construction activities that transpired onsite.** Although the distribution of the amount of photo observations recorded varies widely between DOTs and their projects, over 75 percent of the data collected in HeadLight are photo and narrative observations.

2. **The use of HeadLight varied between DOTs.** The results of the descriptive statistic measures found the distribution of the volume and variety of observations collected in HeadLight varied widely. Some contributing factors that may have influenced the way HeadLight was used include variations in inspection policy and guidelines at the department and project levels, individual's personal preference in recording inspection activities, and the method of integrating HeadLight to traditional inspection workflow processes.

3. **Storing inspection observations as structured data enables different ways to present and visualize the dataset.** Each observation collected in HeadLight is associated with 14 different data fields (e.g., date, time, GPS coordinates, descriptions, contractor tags). Observations and information in the data fields can be searched through and presented in a customized manner, enabling new ways to envision inspection data (Figure 4-3).

4. **Inspection observations can support the data needs of functions performed by asset management and environmental compliance agency offices.** Asset management and environmental compliance personnel often collect data and information that has already been

97

collected during the construction phase. Observations and data in HeadLight can provide (1) asset maintenance division with the complete construction sequence of assets and present information on important field decisions made onsite that can impact the as-built condition and quality of the asset, and (2) environmental compliance agencies with data that describe the time, date, location, and narrative/visual descriptions of environmental compliance issues in a timely manner.

Finally, this study was limited to examining the potential application of the HeadLight dataset for a portion of asset management and environmental compliance activities. The planning, design, construction, and operation of transportation infrastructure systems involve multiple agency offices throughout the organization. Further research can be conducted to investigate other DOT agency offices (e.g., planning, design, etc.) that can benefit from accessing project inspection observations and data.

5.0 Dissertation Summary, Conclusions, and Recommendations

5.1 Summary and Conclusions

This dissertation examines the use of the HeadLight cloud computing technology, developed through a multiphase DOT research initiative, in transportation project inspection. The principal research question for this dissertation is *what is the value of cloud computing technology in transportation construction inspection?* To answer this overarching research question, three individual studies were conducted to determine (1) end user benefits and data quality changes resulting from the use of cloud computing technology when used to replicate traditional inspection processes, (2) how the implementation method of this technology affects its acceptance and adoption, and (3) how this technology and the data collected within can be used beyond its intended project inspection purposes to create additional value throughout the organization. The following sections provide the summary, findings, and contributions of the three studies included in this dissertation.

5.1.1 Chapter 2

Chapter 2 focused on the pilot implementation program where HeadLight was deployed to WSDOT, MnDOT, and TxDOT on 31 projects over a 3-month time span. Field measurements and participant interviews were used to empirically quantify the changes in productivity and data quality from using HeadLight over traditional inspection processes. The finding from this study include:

- Inspectors using HeadLight improved their productivity by saving an average of 1.59 hours per day
- The use of HeadLight improved the volume, variety, completeness, timeliness, and accessibility of inspection data and information

These findings stand as theoretical contributions as limited literature examines the technology's impact on data quality. These findings also contribute to practice by providing transportation agencies with the empirical data needed to help them understand the benefits of investing in cloud computing technology solutions such as HeadLight.

5.1.2 Chapter 3

Chapter 3 presented a case study of the organizational change process associated with WSDOT's year-long research program that deployed HeadLight to 18 project engineering offices across the state. Ultimately, 14 out of the 18 project engineering offices decided to revert to their traditional project

inspection practices. The objective of this study was to understand key organizational change ideas that influence successful technology adoption at a DOT and to produce lessons learned from this case study. A literature review on organizational change management within the construction industry and the change management field produced a set of procedures and factors for successful organizational change management practices. These general organizational change procedures were compared to the change management procedures used by WSDOT to implement HeadLight. The findings from this study include:

- The general advice found in the organizational change management literature work well for technology implementation programs conducted by DOTs
- Consistent involvement of upper management personnel and guiding groups is crucial for a successful change program
- Documentation and workflow process variations across regions or PEOs may become issues in implementing new technologies
- Reliability issues can occur during the early phases of implementing new software

This study contributes to theory by identifying significant organizational change management activities that promote the likelihood of modern technology adoption for DOTs. The study contributes to practice by identifying some lessons learned from the WSDOT case study to help DOTs with similar organizational structures that are interested in deploying modern technology solutions.

5.1.3Chapter 4

The objective of the study presented in Chapter 4 was to understand the current use of HeadLight by DOTs and to provide potential applications of the vast numbers of inspection observations collected beyond project inspection purposes. To understand how HeadLight was being used by DOTs, descriptive statistic measures were used to describe the HeadLight data collected from 11 projects managed by WSDOT, RIDOT, and LADOTD. This study also provided two case that demonstrated how the HeadLight data can be potentially applied to a portion of the work involved in asset management and environmental compliance activities. The findings from this study include:

- Inspectors using HeadLight largely used photo and narrative observations to record and communicate construction activities that transpired on site
- The use of HeadLight varied between DOTs (distribution of the volume and variety of inspection data collected varied widely)

- Inspection observations can support the data needs of functions performed by asset management and environmental compliance agency offices

This study contributes to theory by demonstrating how cloud computing technology, such as the HeadLight, can be used to provide new decision-making insights for construction project management, asset management, and environmental compliance activities. The demonstration of the potential inspection data application also contributes to practice by showing agencies how multiple agency offices can benefit from accessing project inspection data through HeadLight.

5.1.4 Overarching Conclusions

It is worth mentioning that the idea of using mobile devices and cloud computing technology, in itself, is not a significant research finding. Rather, the contribution of this dissertation is determining the value of using such technologies and understanding ways to fully leverage its unique capabilities. Based on the studies included in this dissertation, the principal conclusions of this research are as follows:

- **The efficiency gains and data quality improvements from using cloud computing technology to only mimic traditional or legacy processes show great value.** The quantification of productivity and data quality improvements, discussed in Chapter 2, alone provide better understanding and data needed to justify the investment in this type of technology. However, the technology's utility and value were stunted by only using it to duplicate traditional processes.
- **Consider the cost and effort involved in organizational change management, not just the cost of the technology.** While some cost is certainly incurred purchasing or developing cloud computing technology, there may perhaps be even more in an agency's effort to change processes to a new system and workflow procedures. This is a multifaceted effort involving the following tasks:
  - Establish the need to change
  - Gain commitment and participation from upper management and personnel from all levels of the hierarchy
  - Communicate the change to promote awareness and feedback
  - Create a plan to manage resistance (which is an appropriate behavior)
  - Tailor processes and polices to meet the specific needs of personnel
  - Provide general and continuous training to prepare employees for change and prevent reversion to old conditions

  o Measure and evaluate the change and the change management activities

Failure of implementation efforts are often less due to issues with the technology and more due to instances where some of the above procedures were not followed or only followed to some degree.

- **Implementation of modern technology is not likely to minimize the project inspection process differences between DOTs.** The descriptive statistics presented in Chapter 4 indicate varied use of HeadLight across the DOTs. In some cases, users were content with only mimicking their traditional inspection process and only used a small fraction of the capabilities offered by cloud computing technology.

- **The use of cloud computing capabilities beyond mimicking traditional or legacy processes may offer greater value than those from replicating traditional processes.** As other technology sectors have shown, the true value in using cloud computing technology is realized when users become more familiar with the full capabilities of the technology. The potential applications of applying inspection data for asset management and environmental compliance activities are two examples of ways to use the technology beyond traditional processes.

5.2 Recommendations

Recommendations for further research include:

- **Expand the scope of the HeadLight system to include other aspects of project inspection functions.** The HeadLight system is currently limited to the collection and management of field observations needed to generate daily inspection reports. Inspection personnel are tasked with many other activities, such as material testing, tracking of force account items, and generating payment related documentation. Further benefits can be evaluated by (1) expanding the function of HeadLight to include a larger portion or the entire business processes involved in project inspection, and (2) develop these functions and applications with the mobile and cloud computing technology's full capabilities in mind (rather than duplicating the traditional workflow processes).

- **Examine the cost associated with organizational change management activities.** This dissertation found organizational change management to be an important factor in ensuring the successful adoption of technology. Organizations can better prepare for technology implementation efforts if the cost associated with change management activities are known.

Further research identifying the cost and effort involved in successful change management activities should be investigated.

- **Examine the value of the dataset collected and managed in HeadLight for additional agency offices.** This research demonstrated how the current data collected in HeadLight by three DOTs can be used to further support the decision-making process for construction project management, asset management, and environmental compliance divisions. Future research can gather data from more DOTs and assess the impact of project inspection data for other DOT agency offices (e.g., planning and design).

103

6.0 References

Ahn Yong Han, Kwak Young Hoon, and Suk Sung Joon. (2016). "Contractors' Transformation Strategies for Adopting Building Information Modeling." Journal of Management in Engineering, 32(1), 05015005.

Armenakis, A. A., and Bedeian, A. G. (1999). "Organizational change: a review of theory and research in the 1990s." *Journal of Management*, 25(3), 293–315.

Arnold, P., and Javernick-Will, A. (2013). "Projectwide Access: Key to Effective Implementation of Construction Project Management Software Systems." *Journal of Construction Engineering and Management*, 139(5), 510–518.

Asbahan, R.E., and DiGirolamo, P. (2012). "Value of Tablet Computers in Transportation Construction Inspection." *Transportation Research Record: Journal of the Transportation Research Board, No. 2268*, Transportation Research Board of the National Academies, Washington, D.C., 12–17.

American Society of Civil Engineers (2017). "Infrastructure Report Card: A Comprehensive Assessment of America's Infrastructure." https://www.infrastructurereportcard.org/, Accessed date: 18 September 2017.

Azhar Salman. (2011). "Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry." Leadership and Management in Engineering, 11(3), 241–252.

Bacharach, S. B., Bamberger, P., and Sonnenstuhl, W. J. (1996). "The Organizational Transformation Process: The Micropolitics of Dissonance Reduction and the Alignment of Logics of Action." *Administrative Science Quarterly*, 41(3), 477–506.

Batini, C., Cappiello, C., Francalanci, C., and Maurino, A. (2009). "Methodologies for data quality assessment and improvement." *ACM Computing Surveys*, 41(3), 1–52.

Beer, M., and Nohria, N. (2000). "Breaking the Code of Change." *Harvard Business School Press*.

Bilal, M., Oyedele, L. O., Qadir, J., Munir, K., Ajayi, S. O., Akinade, O. O., Owolabi, H. A., Alaka, H. A., and Pasha, M. (2016). "Big Data in the construction industry: A review of present status, opportunities, and future trends." Advanced Engineering Informatics, 30(3), 500–521.

Boddy, S., Rezgui, Y., Cooper, G., Wetherill, M. (2007). "Computer integrated construction: A review and proposals for future direction." *Advances in Engineering Software*, 38(10), 677–687.

Bovey, W. H., and Hede, A. (2001). "Resistance to organisational change: the role of defence mechanisms." *Journal of Managerial Psychology*, 16(7), 534–548.

Bowden, S., Dorr, A., Thorpe, A., Anumba, C. J., and Gooding, P. (2005). "Making the case for mobile IT in construction." *Computing in Civil Engineering*, 1–12.

Burnes, B., and Jackson, P. (2011). "Success and Failure In Organizational Change: An Exploration of the Role of Values." *Journal of Change Management*, 11(2), 133–162.

Cai, L., and Zhu, Y. (2015). "The Challenges of Data Quality and Data Quality Assessment in the Big Data Era." *Data Science Journal*, 14(0), 2.

Choi, M., and Ruona, W. E. A. (2011). "Individual Readiness for Organizational Change and Its Implications for Human Resource and Organization Development." *Human Resource Development Review*, 10(1), 46–73.

Chong, H.-Y., Wong, J. S., and Wang, X. (2014). "An explanatory case study on cloud computing applications in the built environment." Automation in Construction, 44, 152–162.

Dallavalle C. (1991). "Managing during Organizational Change." *Journal of Management in Engineering*, 7(4), 357–364.

Dossick, C. S., and Sakagami, M. (2008). "Implementing Web-Based Project Management Systems in the United States and Japan." *Journal of Construction Engineering and Management*, 134(3), 189–196.

Emiliani, M. L., and J. Stec, D. (2005). "Leaders lost in transformation." *Leadership & Organization Development Journal*, 26, 370–387.

Erdogan, B., Anumba, C. J., Bouchlaghem, D., and Nielsen, Y. (2008). "Collaboration Environments for Construction: Implementation Case Studies." *Journal of Management in Engineering*, 24(4), 234–244.

Erdogan, B., Anumba, C. J., Bouchlaghem, D., and Nielsen, Y. (2014). "Collaboration Environments for Construction: Management of Organizational Changes." *Journal of Management in Engineering*, 30(3), 04014002.

Federal Highway Administration (2016). "e-Construction Peer-to-Peer Exchange: Summary Report Rhode Island DOT, West Virginia Division of Highways, and Florida DOT." https://www.fhwa.dot.gov/construction/econstruction/peer_exchange/ri_wv_fl.pdf, Accessed date: 21 September 2018.

Federal Highway Administration (2018). "e-Construction Peer-to-Peer Exchange: Summary Report Michigan DOT and Washington DOT." https://www.fhwa.dot.gov/construction/econstruction/peer_exchange/wa_mi.pdf, Accessed date: 18 September 2018.

Fiedler, S. (2010). "Managing resistance in an organizational transformation: A case study from a mobile operator company." *International Journal of Project Management*, Changes & Projects, 28(4), 370–383.

Fosso Wamba, S., Akter, S., Edwards, A., Chopin, G., and Gnanzou, D. (2015). "How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study." *International Journal of Production Economics*, 165, 234–246.

Jagars-Cohen, C. A., Menches, C. L., Jangid, Y. K. and Caldas, C. H. (2009). "Priority-Ranking Workload Reduction Strategies to Address Challenges of Transportation Construction Inspection." *Transportation Research Record: Journal of the Transportation Research Board 2098,* Transportation Research Board, Washington D.C., 13-17.

Janssen, M., van der Voort, H., and Wahyudi, A. (2016). "Factors influencing big data decision-making quality." *Journal of Business Research.*

Kim, A. A., Sadatsafavi, H., and Kim Soucek, M. (2015). "Effective Communication Practices for Implementing ERP for a Large Transportation Agency." Journal of Management in Engineering, 32(3), 04015049.

Kim, Y., Kim, S. (2011). "Cost analysis of information technology-assisted quality inspection using activity-based costing." *Construction Management & Economics*, Vol. 29, 163–172.

Kimoto, K., Endo, K., Iwashita, S., Fujiwara, M. (2005). "The application of PDA as mobile computing system on construction management." *Automation in Construction*, 14(4), 500–511.

Kotter, J. P. (1995). "Leading Change: Why Transformation Efforts Fail." *Harvard Business Review*, 10.

Lines, B. C., Perrenoud, A. J., Sullivan, K. T., Kashiwag, D. T., and Pesek, A. (2016). "Implementing Project Delivery Process Improvements: Identification of Resistance Types and Frequencies." *Journal of Management in Engineering*, 33(1), 04016031.

Lines, B. C., and Vardireddy, P. K. R. (2017). "Drivers of Organizational Change within the AEC Industry: Linking Change Management Practices with Successful Change Adoption." *Journal of Management in Engineering*, 33(6), 04017031.

Liu, L. Y. (2000). "Hand-Held Multimedia Documentation for Tunnel Inspections." *Computing in Civil and Building Engineering*, Proceedings.

Loshin, D. (2006). "Monitoring Data Quality Performance Using Data Quality Metrics." Informatica Corporation, California.

Louisiana Department of Transportation & Development. (2017). *"Construction Contract Administration."* http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Misc%20Documents/Construction%20Contract%20Administration%20Manual/Construction%20Contract%20Administration%20Manual%207-13-17%20Revised.pdf, Accessed date: 06 October 2018.

Louisiana Department of Transportation & Development. (2018). "2018 Federal NHS Transportation Asset Management Plan." http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Data_Collection/Asset%20Management/LADOTD%20TAMP%202018%20Version.pdf, Accessed date: 15 September 2018.

Mao, W., Zhu, Y., and Ahmad, I. (2007). "Applying metadata models to unstructured content of construction documents: A view-based approach." Automation in Construction, 16(2), 242–252.

McCullouch, B. G. (1991). "Automated construction data management system." *Joint Highway Research Project Engineering Experiment Station Purdue University*.

McCullouch, B.G., and Gunn, P. (1993). "Construction field data acquisition with pen-based computers." *J. Constr. Eng. Manage.,* 10.1061/(ASCE)0733-9364(1993)119:2(374), 374–384.

McHugh, M. L. (2012). "Interrater reliability: the kappa statistic." *Biochemia Medica*, 22(3), 276–282.

Minnesota Department of Transportation. (2014). "*Standard Specifications for Construction*." Publication 93594. Minnesota.

Molenaar, K. R., and Gransberg, D. D. (2001). "Design-Builder Selection for Small Highway Projects." *Journal of Management in Engineering*, 17(4), 214–223.

Mostafavi, A., Abraham, D., Noureldin, S., Pankow, G., Novak, J., Walker, R., Hall, K., and George, B. (2013). "Risk-Based Protocol for Inspection of Transportation Construction Projects Undertaken by State Departments of Transportation." *J. Constr. Eng. Manage.,* 139(8), 977-986.

Muhtaroğlu, F. C. P., Demir, S., Obalı, M., and Girgin, C. (2013). "Business model canvas perspective on big data applications." 2013 IEEE International Conference on Big Data, 32–37.

Nguyen, L.D.; Koufakou, A., Mitchell, C. (2015). "A smart mobile app for site inspection and documentation." *Proc., ICSC15 - The Canadian Society for Civil Engineering 5th International/11th Construction Specialty Conference*, University of British Columbia, Vancouver, Canada.

Nikula, U., Jurvanen, C., Gotel, O., and Gause, D. C. (2010). "Empirical validation of the Classic Change Curve on a software technology change project." *Information and Software Technology*, 52(6), 680–696.

Orfaly, R. A., Frances, J. C., Campbell, P., Whittemore, B., Joly, B., and Koh, H. (2005). "Train-the-trainer as an Educational Model in Public Health Preparedness." *Journal of Public Health Management and Practice*, 11(6), S123.

Ozorhon, B., Abbott, C., and Aouad, G. (2013). "Integration and Leadership as Enablers of Innovation in Construction: Case Study." *Journal of Management in Engineering*, 30(2), 256–263.

Raghupathi, W., and Raghupathi, V. (2014). "Big data analytics in healthcare: promise and potential." Health information science and systems, 2(1), 3.

Rhode Island Department of Transportation. (2018). "2018 Transporation Asset Management Plan." http://www.tamptemplate.org/wp-content/uploads/tamps/050_rhodeislanddot.pdf, Accessed date: 27 September 2018.

Rojas, E. M., Dossick, C. S., Schaufelberger, J., Brucker, B. A., Juan, H., and Rutz, C. (2009). "Evaluating Alternative Methods for Capturing As-Built Data for Existing Facilities." *Computing in Civil Engineering*, Proceedings.

Saidi, K.S., Haas, C.T., and Balli, N.A. (2002). "The value of handheld computers in construction." *Proc., 19th International Symposium on Automation and Robotics in Construction*. Special Publication 989. National Institute of Standards and Technology, Gaithersburg, Md., 557-563.

Sanders Steve R., and Eskridge W. Frank. (1993). "Managing Implementation of Change." *Journal of Management in Engineering*, 9(4), 365–381.

Shah, K., Mithcell, A., Lee, D., and Mallela, J. (2017). "Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction)." Publication FHWA-HIF-17-028. Federal Highway Administration.

Shi, Q., and Abdel-Aty, M. (2015). "Big Data applications in real-time traffic operation and safety monitoring and improvement on urban expressways." Transportation Research Part C: Emerging Technologies, 58, 380–394.

107

Snow, M., White, G., Katara, S., Willoughby, K., Garcia, R. (2013). "Project Inspection Using Mobile Technology—Phase I: An investigation into existing business processes and areas for improvement using mobile technology." *Publication WA-RD 840.1*. Washington State Department of Transportation.

Sutanto, J., Kankanhalli, A., Tay, J., Raman, K. S., and Tan, B. C. Y. (2008). "Change Management in Interorganizational Systems for the Public." *Journal of Management Information Systems*, 25(3), 133–175.

Taylor, T. R. B., and Maloney, W. F. (2013). *NCHRP Synthesis 450: Forecasting Highway Construction Staffing Requirements*. Transportation Research Board, Washington, D.C.

Texas Department of Transportation. (2004). "Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges." Texas.

Texas Department of Transportation. (2013). "*TxDOT Glossary.*" Texas.

The PFM Group. (2016). *Washington State Department of Transportation Recruitment and Retention Study*. Government, Washington State Department of Transportation, 109.

Transportation Research Board. (2003). "The Workforce Challenge: Recruiting, Training, and Retaining Qualified Workers for Transportation and Transit Agencies – Special Report 275." Transportation Research Board of the National Academies.

Valdes, D., and Perdomo, J. (2013). "Using Mobile Computers to Automate the Inspection Process for Highway Construction Projects." University Transportation Research Center-Region 2, New York.

Wand, Y., and Wang, R. Y. (1996). "Anchoring Data Quality Dimensions in Ontological Foundations." *Commun. ACM*, 39(11), 86–95.

Warne, Thomas R. (2003). "State DOT Outsourcing and Private-Sector Utilization." *NCHRP Synthesis 313,* Transportation Research Board of the National Academies. Washington D.C.

Washington State Department of Transportation. (2012). "Construction Training Guide for Local Agencies." *Publication M 3075.01*. Washington.

Washington State Department of Transportation. (2014). "Standard Specifications for Road, Bridge, and Municipal Construction." *Publication M 41-10*. Washington.

Washington State Department of Transportation. (2015). "Construction Manual." *Publication M41-0.22*. Washington.

Washington State Department of Transportation. (2018). "Transportation Asset Management Plan." https://www.wsdot.wa.gov/sites/default/files/2018/08/15/Washington-State-DOT-Initial-Transportation-Asset-Management-Plan.pdf, Accessed date: 08 October 2018.

Wilkinson, P. (2005). *Construction collaboration technologies: the extranet evolution*. Taylor & Francis, London; New York.

Won, J., Lee, G., Dossick, C., and Messner, J. (2013). "Where to Focus for Successful Adoption of Building Information Modeling within Organization." *Journal of Construction Engineering and Management*, 139(11), 04013014.

Yamaura, J., White, G., Katara, S., Willoughby, K., Garcia, R., and Beer, M. (2015). *Project Inspection Using Mobile Technology – Phase II: Assessing the impacts of mobile technology on project inspection*. Washington State Department of Transportation, Olympia, WA, 121.

Yuan, C., McClure, T., Cai, H., and Dunston, P. S. (2017). "Life-Cycle Approach to Collecting, Managing, and Sharing Transportation Infrastructure Asset Data." Journal of Construction Engineering and Management, 143(6), 04017001.

Zhang, H., Chi, S., Yang, J., Nepal, M., and Moon, S. (2016). "Development of a Safety Inspection Framework on Construction Sites Using Mobile Computing." *Journal of Management in Engineering*, 33(3), 04016048.

Appendix A: Data Collection Guide
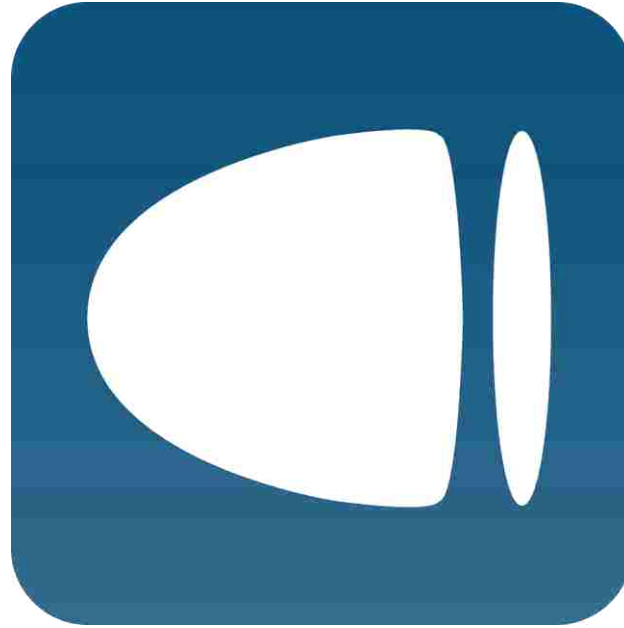
HeadLight

MPI Pilot Project – Field Data Collection Guide

Version 9/22/2014

Inspector:

110

Field Preparation Checklist

Be sure to have the following items with you out in the field

Personal Protective Equipment (PPE)

- ☐ Steel-toed (or comparable) boots
- ☐ Jeans
- ☐ Safety vest
- ☐ Safety glasses
- ☐ Hardhat
- ☐ Earplugs

Other Materials

- ☐ iPad & battery charging chords
- ☐ Stopwatch
- ☐ Field Data Collection Guide

The First Week – Help & Support

During the first week, we want to make sure that field inspectors are getting familiar with HeadLight. This week will mostly be spent answering questions and providing support for the inspectors.

We will collect inspector and project related information as well as some basic "over-the-shoulder" observations on how the inspectors are using HeadLight and the Tool Kit. Please use the following form to collect the information.

Inspector & Project Information

Inspector Name:	Project Name:
Inspector's tentative schedule for the next month:	
Site Parking Instructions:	

The First Week – Help & Support

Pavia research diary log – Use the form below to summarize each visit.

Initial	Date	Summary

113

The First Week – Help & Support

Initial Observations and things to look for

Is the inspector using anything other than an iPad or HeadLight to record observations?
Are observations created for the correct project?
What kinds of observations are most often used?
How are observations created? Any usual processes involved?
Are time-by-time diary entries created using one text observation for each entry?
Are IDRs created at the end of the shift
Are equipment observations made for each individual equipment/machinery?
Any frustrations encountered so far?

114

Weeks 2 through 3 – Data Collection

1) Measure how long it takes to create observations using a stopwatch. Try to get 16 measurements per week (Create 4 observation types, 4 times each)

Observation	Date	Obsv. Type	Time (sec)	Notes
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				

115

Weeks 2 through 3 – Data Collection

2) Measure how long it takes to create IDRs using a stopwatch. Try to get 4 measurements per week.

*If this measurement happens mid-shift, delete the IDR after the observation to avoid duplicates

IDR	Date	Time (sec)	Notes
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			

Weeks 2 through 3 – Data Collection

3) Measure how long it takes to search for content in Dropbox using stopwatch. Try to get 2 measurements per week.

*If inspector has previously searched for something in Dropbox, have them reenact those steps

Measurements	Date	Search topic	Time (min)	Notes
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

117

Weeks 2 through 3 – Data Collection

4) Verbal questions - How much time is being spent in the field versus the field office?

*Can be interpreted by percentage of their time.

Measurement	Date	Percentage of time spent in field	Reason to return to office
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

118

Weeks 2 through 3 – Data Collection

5) Verbal question - What type of documents have been accessed in Dropbox so far? Try to get 2 measurements per week.

Measurement	Date	Document type/title
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

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Week 4 – Benchmarks and Post Pilot Interview

Week 4 will capture the inspector's typical process for recording observations and how they use that information to create daily reports and other important documents and reports. The following questions can help create benchmark notes for each inspector.

Observation Method

- How are observations made? Do they use a field notebook, camera, etc.?
- Is he/she using any mobile device/tools to help record observations?
- What type of obsevations are made?
- How long does it take to record a typical observation?

Daily Report Method

- How many observations are typically included in the daily report?
- What kind of format (.xlsx, pdf, etc.) is the report in?
- What are the process invovled in creating these reports?
- How are attachements like photos included in these reports?
- How long does it take to create the reports?
- When are these reports being made?

The post pilot interview questions can be found in our Dropbox account.

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Appendix B: Field Personnel Interview Guide

Background
1) How long have you been in the inspector role?
2) How long have you been creating IDRs? How long have been creating IDRs using the most current method?
3) How long did it take you to become comfortable with creating IDRs using the current process?
4) Do you own a tablet computer? Have you used one before the pilot program?
5) How experienced are you in using tablets and smartphones. (1 = not experienced, 5 = extremely experienced)
6) Did your experience with other mobile services or products make it easier to operate the HeadLight application and the inspector's tool kit. (1 = strongly disagree, 5 = strongly agree)
7) In a typical week, how often do you have to look up information in the project plan, specs, and other project references out in the field?
   a. How do you look up this information (hard copy, electronic, etc.)?
   b. How long does it typically take to look up information?

Learnability
8) Did you get used to using the HeadLight app?
9) How long did it take until you were comfortable?
10) After you were comfortable, did you want to give it up?
11) Describe your experience learning how to use HeadLight and the Inspector's Tool Kit.
12) It was easy to learn to use the HeadLight application. (1 = strongly disagree, 5 = strongly agree)

Usability
13) Describe how using HeadLight has changed the way you observe activities out in the field.
14) Describe how using HeadLight has changed the way you create Inspector Daily Reports.
15) On a scale of 1 to 5 (1=not useful, 5 = extremely useful), rate the following features: (Bold items were referenced in the Phase 1 report)
   a. **Photo observations with annotations integrated with notes.**
   b. **Metadata**
      i. **Timestamp**
      ii. **Location tag/Map View**
      iii. **e-signature**
      iv. **Priority flag**
   c. **Equipment observation**
   d. **Personnel observation**
   e. **Weather observation**
   f. **QR create/QR scan observation**
   g. Video observation

h.   Audio observation
i.   Density observation
j.   Text observation
k.   Temperature observation
l.   Start/Stop observation
m.   Material observation

16) It is easy to create observations using HeadLight compared to my previous method. (1 = strongly disagree, 5 = strongly agree) Please explain some differences with specific features, such as including photos to IDRs.
17) It is easy to create IDRs using HeadLight compared to my previous method. (1 = strongly disagree, 5 = strongly agree) Please explain the differences.

Efficiency
18) Describe the impact of using HeadLight when compared to the previous method for the following:
   a.   Creating observations
   b.   Creating IDRs
   c.   Searching for information in plans, specs, and other resources
   d.   Performing calculations
19) I can complete my work tasks quickly by using HeadLight and the inspector's tool kit compared to my previous method. (1 = strongly disagree, 5 = strongly agree)
20) The HeadLight app responds quickly to my actions. (1 = strongly disagree, 5 = strongly agree)

Effectiveness
21) Describe your experience in entering information to create observations.
22) Describe your experience in viewing the information entered into HeadLight.
23) HeadLight and the Inspector's Tool Kit enables quick and effective performance of work tasks. (1 = strongly disagree, 5 = strongly agree)
24) Do you feel you were able to collect more information, the same amount of information, or less information in the field using the pilot system vs. your previous method? Please explain.

User Satisfaction
25) Describe how you feel about HeadLight's user interface.
26) If you could create and submit your entire IDR in the field similar to your experience in the pilot program, would you prefer that to your previous method? How much of an impact do you think this would have on your job performance?
27) I would recommend the use of HeadLight and the Inspector's Tool Kit for other inspectors doing the same work. (1 = strongly disagree, 5 = strongly agree)
28) What was your favorite feature of HeadLight?
29) What was your least favorite feature of HeadLight?

Factors Related to Mobile Work Context
30) Inputting information into HeadLight is easy. (1 = strongly disagree, 5 = strongly agree)

122

31) Did the environment of the jobsite impact your use of the iPad and HeadLight?
   a. Sunshine makes the use of iPad and HeadLight difficult. (1 = strongly disagree, 5 = strongly agree)
   b. Darkness makes the use of iPad and HeadLight difficult. (1 = strongly disagree, 5 = strongly agree)
   c. Dust and dirt makes the use of iPad and HeadLight difficult. (1 = strongly disagree, 5 = strongly agree)
   d. Noise makes the use of iPad and HeadLight difficult. (1 = strongly disagree, 5 = strongly agree)
   e. Outside temperature makes the use of iPad and HeadLight difficult. (1 = strongly disagree, 5 = strongly agree)
32) The use of HeadLight on the iPad suits well for performing my work tasks while on the move. (1 = strongly disagree, 5 = strongly agree)
33) Making observations and IDRs available to my supervisor/management is easy. (1 = strongly disagree, 5 = strongly agree)

Safety
34) Describe any safety concerns while using HeadLight and the Inspector's Tool Kit out in the field?
35) The use of the mobile tools included in the iPad has caused me safety risks while on the move. (1 = strongly disagree, 5 = strongly agree)
36) I sometimes get so busy that I have little time to make observations and IDRs the same day. (1 = strongly disagree, 5 = strongly agree)
37) It is easy to perform work tasks in a hurry with HeadLight and the Inspector's Tool Kit. (1 = strongly disagree, 5 = strongly agree)

Support
38) Did you seek help from our support staff or the support call center? (Yes/No) ***If no, skip to next section*
39) Describe your experience in receiving support from the support staff.
40) I always know who to ask for help if I have problems performing work tasks with HeadLight and the Inspector's Tool Kit. (1 = strongly disagree, 5 = strongly agree)
41) The help information given by the support call center and staff is useful. (1 = strongly disagree, 5 = strongly agree)

Impacts on Mobile Work Productivity
42) Using HeadLight and the Inspector's Tool Kit on the iPad in my job reduces travelling from and to the office during the workday. (1 = strongly disagree, 5 = strongly agree)
43) Using HeadLight and the Inspector's Tool Kit on the iPad helps me complete my work tasks quickly. (1 = strongly disagree, 5 = strongly agree)

Baseline Comparison
44) I would prefer to have an iPad on the jobsite to a laptop for field use. (Yes/No)
45) If HeadLight was tied in fully to WSDOT's process, for example where bid items were automatically available and output formats were exactly tied to WSDOT forms for

IDRs, FNRs, Force Account, etc., how beneficial would these capabilities be for your job? (1 = not beneficial, 5 = extremely beneficial)

46) HeadLight was a pilot to aid in field data collection for our job. After spending several weeks with it, what are the features you can't live without? What are the features you'd like to see? And looking to your whole job of ensuring proper documentation of the job, what do you feel are the most important additional capabilities that should be incorporated next to eliminate the need for you to return to the office?

47) Is there anything else about the pilot experience that you feel is important to share with us?

Appendix C: Office Personnel Interview Guide

Background
1) How long have you been in your current role (chief inspector, APE, PE, etc.)?
2) How often did you use HeadLight to access observations and IDRs?
3) What was your main reason for using the system?

Learnability
4) Describe your experience learning how to use HeadLight web service.
5) How easy was it to learn to use the HeadLight web service. (1 = not easy, 5 = extremely easy)

Usability
6) Describe how using the HeadLight web service changed the way you access observation activities out in the field.
7) Describe how using the HeadLight web service changed the way you review Inspector Daily Reports.
8) On a scale of 1 to 5 (1=not useful, 5 = extremely useful), rate the following features that can be included in IDRs: (Bold items were referenced in the Phase 1 report)
   a. **Photo observations with annotations integrated with notes.**
   b. **Metadata**
        i. **Timestamp**
       ii. **Location tag/Map View**
      iii. **e-signature**
       iv. **Priority flag**
   c. **Equipment observation**
   d. **Personnel observation**
   e. **Weather observation**
   f. **QR create/QR scan observation**
   g. Video observation
   h. Audio observation
   i. Density observation
   j. Text observation
   k. Temperature observation
   l. Start/Stop observation
   m. Material observation
9) How easy is it to navigate the HeadLight web service. (1 = not easy, 5 = very easy)
10) How easy is it to review IDRs using the HeadLight web service. (1 = not easy, 5 = very easy)

Efficiency
11) How beneficial is it for you to have information provided and accessible throughout the day on each active jobsite? (1 = not beneficial, 5 = extremely beneficial) Please describe why.
12) Describe changes in your productivity in reviewing IDRs.

13) How quickly can you complete your task by using the HeadLight web service? (1 = not quickly, 5 = very quickly)
14) Were IDRs available for review in a more timely manner using the HeadLight system compared to the previous method? Please explain. (If yes, what was the impact of having information available in real-time?)

Effectiveness
15) Describe your experience in reviewing observations and IDRs using the HeadLight web service.
16) Do you feel that the IDRs created by HeadLight capture more information, the same amount of information, or less information compared to the previous method?

User Satisfaction
17) Describe how you feel about the HeadLight web service's user interface.
18) Would you prefer to review IDRs using the HeadLight web service compared to the previous method? If yes, how much of an impact would the HeadLight web service have on your job performance?
19) What was your favorite feature on the HeadLight web service?
20) What was your least favorite feature on the HeadLight web service?
21) Would you recommend the use of HeadLight and the web service for others doing the same work? (1 = not recommend, 5 = strongly recommend)

Searching & Reporting
22) Describe how useful it would be to incorporate a search function to enable searches for specific information?
23) What type of reports (trends across projects, etc.) would you like to generate from the information collected by HeadLight?

Support
24) Did you seek help from our support staff or the support call center during the pilot program? (Yes/No) ***If no, skip to next section*
25) Describe your experience in receiving support from the support staff.
26) I always know who to ask for help if I have problems performing work tasks with the HeadLight web service. (1 = strongly disagree, 5 = strongly agree)
27) How useful was the help information given by the support call center and staff? (1 = not helpful, 5 = extremely helpful)

Impacts on Mobile Work Productivity
28) Did the use of the HeadLight web service in your job reduce travelling from and to the field during the workday. (1 = strongly disagree, 5 = strongly agree)

Baseline Comparison
29) I would prefer reviewing and approving documents, such as IDRs, using the HeadLight web service to other methods. (Yes/No)
30) If HeadLight system was tied in fully to WSDOT's process, for example where bid items were automatically available and output formats were exactly tied to WSDOT

126

forms for IDRs, FNRs, Force Account, etc., how beneficial would these capabilities be for your job? (1 = not beneficial, 5 = extremely beneficial)

31) HeadLight was a pilot to aid in field data collection for our job. After spending several weeks with it, what are the features you can't live without? What are the features you'd like to see? And looking to your whole job of ensuring proper documentation of the job, what do you feel are the most important additional capabilities that should be incorporated into HeadLight?

32) What other areas for your project office could HeadLight help? (i.e. Pay Notes, Force Account, etc.)

33) Is there anything else about the pilot experience that you feel is important to share with us?