MID-AMERICA TRANSPORTATION CENTER

Report # MATC-ISU: 238

Final Report
WBS: 25 1121 0003 238

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Framework for Advanced Daily Work Report System

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2015

A Cooperative Research Project sponsored by
U.S. Department of Transportation-Research
and Innovative Technology Administration

MATC

Framework for Advanced Daily Work Report System

Final Report about Construction Engineering

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A Report on Research Sponsored by

Mid-America Transportation Center
University of Nebraska-Lincoln

February 2015

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
WBS: 25-1121-003-238		

4. Title and Subtitle	5. Report Date
Framework for Advanced Daily Work Report System	February 2015
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
H. David Jeong, Douglas D. Gransberg, and K. Joseph Shrestha	25-1121-0003-238
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Institute for Transportation Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664	**11. Contract or Grant No.** DTRT12-G-UTC07
12. Sponsoring Organization Name and Address	**13. Type of Report and Period Covered**
Mid-America Transportation Center, 2200 Vine Street, PO Box 830851, Lincoln, NE 68583-085 U.S. DOT Research and Innovative Technology Administration (RITA) and Federal Highway Administration, 1200 New Jersey Avenue, SE, Washington, DC 20590	Final Report about Construction Engineering **14. Sponsoring Agency Code** MATC TRB RiP No. 34771

15. Supplementary Notes

Visit www.intrans.iastate.edu for color pdfs of this and other research reports.

16. Abstract

A significant amount of time and effort is invested to collect and document various field activity data of a highway project in Daily Work Report (DWR). Although there are many potential benefits of DWR data, the current use of the data is very limited. The objective of this study is to develop an ideal framework for an advanced DWR system to improve the DWR data collection and utilization practices. A literature review and two surveys were conducted to investigate the current practices of collecting DWR data, utilization of the data, and challenges associated with advanced collection and utilization of DWR data. The study found that there is a huge gap between the current and potential level of benefits of DWR data. The challenges for better collection and utilization of DWR data were identified and classified. An ideal framework for an advanced DWR system was developed to overcome those challenges. The ideal framework consists of seven major components: a) data attributes and its relations, b) integration with existing systems, c) visualization of data, d) advanced data collection systems, e) automation of DWR data analysis and reporting, f) human factors, and g) other technical aspects. The framework can be used by state DOTs to improve an existing DWR system or to develop a new system. The implementation of the framework is expected to improve the level of DWR data collection and utilization practices in state DOTs.

17. Key Words	18. Distribution Statement
construction data utilization—construction field data—Daily Work Report (DWR)—inspector's daily report (IDR)—residential construction engineer	No restrictions.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	150	NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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LIST OF ABBREVIATIONS

AASHTOWare FieldBook (AFB)
AASHTOWare FieldManager (AFM)
AASHTOWare SiteManager (ASM)
Alabama Department of Transportation (ALDOT)
American Association of Highway and Transportation Officials (AASHTO)
Arkansas Highway and Transportation Department (AHTD)
Artificial Neural Network (ANN)
As-Built But-For (ABBF)
Automated Machine Guidance (AMG)
Average Annual Daily Traffic (AADT)
California Construction Management System (CCMS)
California Department of Transportation (Caltrans)
Commercial Off-The-Shelf (COTS)
Construction and Material Management System (CAMMS)
Construction Documentation System (CDS)
Construction Management and Reporting (CMR)
Construction Management System (CMS)
Construction Measurement and Payment System (CM&P)
Construction Record System (CORS)
Contract Administration System (CAS)
Cost To Date (CTD)
Critical Path Method (CPM)
Daily Work Report (DWR)
Department of Transportation (DOT)
Disabled Business Enterprise (DBE)
Entity-Relation (ER)
Equal Employment Opportunity (EEO)
Federal Highway Administration (FHWA)
Field Automated Communication Systems (FACS)
Field Data Collection (FDC)
FieldManager (FM)
Freedom of Information Act (FOIA)
Geographic Information System (GIS)
Global Positioning System (GPS)
Graphical User Interface (GUI)
Hypertext Transfer Protocol (HTTP)
Hypertext Transfer Protocol Secure (HTTPS)
Illinois Construction Records System (ICORS)
Industrial Engineering (IE)
Information and Communication Technology (ITC)
Inspector's Daily Report (IDR)
Internet of Things (IoTs)
Kansas Construction Management System (KCMS)
Knowledge Discovery in Databases (KDD)

Light Detection and Ranging (LiDAR)
Linear Referencing System (LRS)
Maintaining Assets for Transportation System (MATS)
Michigan Department of Transportation (MDOT)
Mid-America Transportation Center (MATC)
National Institute of Science and Technology (NIST)
Next Generation (NeXtGen)
Paper-based Only (PBO)
Pennsylvania Department of Transportation (PennDOT)
Personal Computer (PC)
Primary Key (PK)
Progress Controlling Operation (PCO)
Project Development Business System (PDBS)
Project Site Activities (PSA)
Quality Assurance/Quality Control (QC/QA)
Radio Frequency (RF)
Radio Frequency Identification (RFID)
Relational Database Management System (RDBMS)
Request for Information (RFI)
Resident Construction Engineer (RCE)
Semi-Parametric Weather Generator (SWG)
SiteManager Access Reporting (SARS)
South Dakota (SD)
South Dakota Construction Management System (SD CMS)
Structured Query Language (SQL)
Support Vector Machine (SVM)
User Interface (UI)
Utah Department of Transportation (UDOT)

ACKNOWLEDGMENTS

The authors would like to thank the Mid-America Transportation Center (MATC) and U. S. Department of Transportation (DOT) Research and Innovative Technology Administration (RITA) for sponsoring this research. The authors would also like to thank the state DOT personnel and contractors for providing valuable information and expert opinions for the study.

DISCLAIMER

ABSTRACT

A significant amount of time and effort is invested to collect and document various field activity data of a highway project in Daily Work Report (DWR). Although there are many potential benefits of DWR data, the current use of the data is very limited. The objective of this study is to develop an ideal framework for an advanced DWR system to improve the DWR data collection and utilization practices. A literature review and two surveys were conducted to investigate the current practices of collecting DWR data, utilization of the data, and challenges associated with advanced collection and utilization of DWR data. The study found that there is a huge gap between the current and potential level of benefits of DWR data. The challenges for better collection and utilization of DWR data were identified and classified. An ideal framework for an advanced DWR system was developed to overcome those challenges. The ideal framework consists of seven major components: a) data attributes and its relations, b) integration with existing systems, c) visualization of data, d) advanced data collection systems, e) automation of DWR data analysis and reporting, f) human factors, and g) other technical aspects. The framework can be used by state DOTs to improve an existing DWR system or to develop a new system. The implementation of the framework is expected to improve the level of DWR data collection and utilization practices in state DOTs.

EXECUTIVE SUMMARY

The purpose of this study is to develop a conceptual framework for an advanced Daily Work Report (DWR) system that can be used for better collection and utilization of DWR data in state DOTs. The study investigated the current level of data being collected and its applications. It further investigated and identified possible reasons behind the limited applications of the data. A conceptual ideal framework for advanced DWR system was developed based on the literature review and two surveys and it was validated by experts.

Currently, most state DOTs use DWR data for limited applications such as progress monitoring, contractor payment, and claim and dispute resolution. However, DWR data can be effectively used for much wider applications including production rate estimation, contract time determination, and analyses of weather effect on contract time, as-built information generation, activity cost estimation, project risks identification, contractor evaluation, safety analyses, and evaluation of innovative contracting methods.

Using two nationwide surveys, this study identified various challenges to effective collection and utilization of DWR data for wider applications. Those challenges were categorized into six areas: a) quality of data, b) resources limitation, c) duplication of efforts, d) lack of proper data attributes, e) technical limitations, and f) current business practices. The study also found that the automation of DWR data analysis for a specific application is highly desirable as a manual analysis process would be extremely time consuming due to the extensive amount of historical DWR data.

Finally, a framework for an advanced DWR system for state DOTs was developed based on the findings of the study. The framework consisted of seven major components: a) data attributes and its relations, b) integration with existing systems, c) visualization of data, d) advanced data collection systems, e) automation of DWR analysis and reporting, f) human factors, and g) other technical aspects. The framework was developed to overcome the challenges associated with the collection and utilization of the DWR data. The framework was validated by seven DWR experts. The framework can be used as a comprehensive reference to updating existing DWR systems or developing a new DWR system. The use of the framework is expected to significantly improve the DWR data collection as well as utilization in state DOTs.

1 INTRODUCTION

1.1 Background and Overview

Construction projects are associated with the collection, processing, and exchange of large amounts of data among project stakeholders (Cox, Perdomo, and Thabet 2002). Some of those data collected and exchanged during construction are project correspondence, memorandums, request for information, change order requests, quality control reports, construction progress, field activities, labor hours, equipment hours, and material stockpiles. Traditionally, those data generated during construction are recorded in paper-based media. Later, with the invention of electronic devices and the ease of recording and analyzing in those devices, electronic systems were introduced in the construction industry as early as 1968 (Caltrans 2010). Those data can be useful not only to keep track of current projects but also to improve future project executions.

One of the data sets collected by state DOTs during the construction stage is called Daily Work Report (DWR) data. DWR data include various types of work performed, quantities of work performed, equipment usage, labor hours, materials used, inspection results, significant conversations with contractors, and visitors. State DOTs provide instructions to inspectors and Residential Construction Engineers in their construction manuals regarding the various data to be collected in their DWR systems (Connecticut DOT 2011; Iowa DOT 2004). Inspectors and Residential Construction Engineers (RCEs) collect those DWR data while inspecting construction activities either using the traditional method of paper-based DWR systems or the relatively recent method of electronic DWR systems. Ideally, DWR data should be collected every day, and many state DOTs use the data to estimate the payment for the contractor. Another major reason behind collection of DWR data is to ensure that state DOTs have sufficient data and evidence in case of claims and disputes to make appropriate compensations for extra work or delays caused by scenarios like differing site conditions and unfavorable weather. State DOTs also collect DWR data to keep track of the project progress in terms of total expenditure to date, total working days used, and total quantities of works completed.

A study showed that as much as 50% of Resident Construction Engineers' (RCEs') time is spent on collecting DWR data in the field (McCullouch and Gunn 1993). Over the time such efforts have resulted in a significant increase in the amount of DWR data collected and stored. In a traditional paper-based environment, state DOTs have collected piles of DWR forms stacked in storage rooms. In an electronic environment, the size of DWR data has been increasing massively over time as well. For example, one DWR database obtained from one of the state DOTs has more than 4,000,000 lines of linguistic remarks along with more than 600,000 records regarding the quantities of work performed every day. In paper-based DWR systems, analyzing such massive amounts of data becomes next to impossible. Even in an electronic system, analyzing such large data to obtain useful insights from them becomes more challenging with manual and traditional statistical data analysis techniques. This necessitates automation and the use of data mining techniques such as pattern analyses and predictive analytics to obtain more benefits from the data already collected. With the availability of structured electronic data recording systems and advanced data mining techniques, more benefits can be obtained from DWR data. Some of the possible applications of DWR data collected with proper data attributes and proper data relationships include generating as-built costs and schedules, production rate estimation, contract time determination for future projects, impact of weather events, activity cost estimation, and evaluating effects of innovative contracting methods. Most of those benefits of the DWR data have not been realized by many state DOTs, which may be because detailed data are not collected or because the data collected are in linguistic format rather than structured data format. The reason behind not collecting such detailed data might be insufficient DOT resources required to collect those data. This scenario can possibly be improved by utilizing automated data collection systems, which can improve the quality of data being collected and in turn will increase the level of benefits that can be obtained from the data. The scenario can be further improved by identifying proper data structures that are necessary to obtain those benefits so that various analyses required to obtain such benefits can be automated. Those changes can improve the decision making processes in state DOTs, such as

- Determination of more appropriate contract time that can reduce the road users' discomfort by completing the projects with least time with due consideration for economic aspects,
- Identification of potential issues with specific project types from the very beginning so that mitigating measures can be taken before such issues occur, and
- Determination of proper project sequencing to optimize the number of projects that can be monitored by available state DOT inspector and RCEs.

1.2 Problem Statement

A lot of time is spent collecting Daily Work Report (DWR) data in construction sites. The collection of a vast amount of DWR data has been eased by electronic DWR systems. The use of such electronic DWR and contract management systems has resulted in savings of millions of dollars each year for state DOTs (McCullouch 1991; Fowler 2010; Couto 2005). However, the use of such extensive data has probably been limited mostly to progress monitoring, contractor payment, and dispute resolution (A. K. Woldesenbet, Jeong, and Lewis 2014). The data can potentially be used to quantify the effect of weather on schedule and duration of future projects, identify the trend of cost and quantity overrun in various types of projects over time, improve the design and specifications of future projects, and perform work zone safety analyses. But, many problems still exist for better collection and utilization of DWR data. Some of the possible reasons for such limited use might be lack of understanding of the level of data being collected, lack of structured data attributes, and lack of proper automated methodologies for applications and benefits of the data. Tackling such problems is necessary to improve the utilization of DWR data that will increase the savings as well as returns on investment. Thus, it is necessary to study existing challenges to improve the use of the data and develop a proper framework to overcome those challenges.

1.3 Research Objectives

The ultimate goals of this study are a) to improve the current level of benefits obtained from DWR data that is already collected and b) to improve the data collection practices to increase the possible level of applications and benefits. The objectives of the study are:

- To review current practices of collecting, storing, and analyzing DWR data,
- To identify current and possible applications and benefits of DWR data and challenges faced by state DOTs to better utilize DWR data, and
- To develop a framework for better collection and utilization of DWR data.

1.4 Expected Results and Contributions

The study presents the current practices and challenges of collection and utilization of DWR data and proposes a framework based on the findings of the study. The proposed framework is expected to be useful in developing a new electronic DWR system or improving existing DWR systems. The framework is expected to:

- Improve the quality and usability of DWR data collected,
- Enable automation of DWR data analyses and reporting,
- Enable analyses of DWR data with data from other systems,
- Generate useful decisions from planning stages to the construction stages for future projects, and
- Improve the level of applications and benefits obtained from DWR data.

Overall, it is expected to improve the decision making processes of state DOTs by making use of data-driven decisions.

1.5 Report Organization

2 presents the review of the existing literature regarding the current practices of DWR data collection and utilization along with a review of existing DWR systems. A detailed research methodology is presented in 3. In 4, the results of two nationwide surveys, interviews of Iowa DOT RCEs, and contractor interviews are presented. The framework for advanced DWR system is presented in 5 followed by conclusions and recommendations in 6.

2 LITERATURE REVIEW

This chapter presents findings from an extensive review of literature related to the collection and use of Daily Work Report (DWR) data and systems being used to collect and analyze the data. The chapter starts by introducing the concept of DWR data followed by Residential Engineers' responsibilities and DWR data collection practices as found from state DOT manuals. Currently documented applications and benefits of the DWR data are presented afterward, followed by the evolution of DWR systems from paper-based DWR systems to current electronic DWR systems. The electronic DWR systems being used by state DOTs are then reviewed in terms of data attributes that can be collected from the systems. After that, some Commercial Off-The-Shelf (COTS) systems for DWR applications are reviewed briefly to understand the gap between those systems with the state DOT developed systems.

2.1 Definition of Daily Work Report (DWR)

Construction projects are associated with the collection, processing, and exchange of large amounts of data among project stakeholders (Cox, Perdomo, and Thabet 2002). The data collected in each stage of a project lifecycle is transferred to the next stage and can be used for making various decisions. For example, the quantity of work to be done, estimated time, and the lowest bids that are determined during the design development, and bid letting stages are used to monitor the progress of the project in terms of quantity, time, and costs during the construction stage.

A lot of data such as various works performed, quantities of works performed, equipment usage, labor hours, materials used, inspection results, traffic control, significant conversations with contractors such as instructions given to the contractors and conversations regarding potential claims, and visitors are collected during the construction phase by inspectors and Resident Construction Engineers (RCEs) and the data are stored in a system. This data is commonly known as Daily Work Report (DWR) data. DWR data is considered to be the most important record kept by inspectors (Alabama DOT 2013). In general, inspectors collect more detailed data, and the data collected is called DWR data, while RCEs collect more important but concise data for the day in linguistic format, which is generally referred to as daily diary. For example, MnDOT (2007) contract administration manual suggests that inspectors' DWR should include, as necessary, the data regarding labor and equipment hours, materials used, a detailed description of works, location of works, quantities of works, construction methods used, weather conditions, reasons of delays, instructions given to the contractors, and extra work agreements made. At the same time, the manual suggests that Engineers do not necessarily have to keep a diary but, if required, should record data with a focus on events, instructions, situations, and circumstance and work performed each day. Although, it still lists the DWR data listed above for the inspectors as possible data that can be collected in the diary. Similarly, AFM DWR (or IDR) can be used to record data related to general, contractors, site times, postings, attachments, and view categories while a daily diary can be used to record data related to general, site times, attachments, and views categories (AASHTO 2014a). For this study, the daily diary is also considered as a part of the DWR.

It should also be noted that state Departments of Transportation (DOTs) also use various terms for DWR data which include Inspector's Daily Report, Daily Report, Inspection Daily Report, and Inspector's Report. For the purpose of this study, the term DWR is used throughout the study. Similarly, the responsibility of collecting DWR data is assigned to personnel with various titles depending on the state. A short list of personnel responsible for collecting DWR data in various states is presented in Table 2.1.

Table 2.1 Personnel responsible for collecting DWR by state

State	Personnel responsible for collecting DWR data
Delaware	Inspectors and Area Engineers
Vermont	Supervisors and Time Keepers
New Jersey	Inspectors, Office Engineers, and Party Resident Engineers
Alabama	Inspectors, Party Chief, and Assistant Project Engineers
California	Assistant Resident Engineers and Resident Engineers
Iowa	Inspectors and Residential Construction Engineers (RCEs)

For the purpose of this study, the terms "inspectors" and "Residential Construction Engineers" (RCEs) will be used throughout the report to represent the DOT personnel responsible for DWR data collection and analyses.

2.2 Resident Construction Engineers' (RCEs') Responsibilities and Current DWR Data Collection Practices

As stated previously, inspectors and RCEs are responsible for the collection and analyses of DWR data. They are also responsible for ensuring that the contractors perform the works as mentioned in the contract and documents the progress (Caltrans 2013b). Additionally, Connecticut DOT (2011) has listed the following responsibilities for RCEs:

- Determine the level of staffing required for the project,
- Approve the DWRs,
- Approve change orders,
- Review and approve agreed prices for extra work,
- Review and approve time extensions,
- Authorize suspension of a contract (in cases like non-compliance to state DOT requirements as noted in DWR).

Similarly, in Connecticut DOT, RCEs are assigned various responsibilities regarding the monitoring of the construction projects which are listed below (Connecticut DOT 2011):

- Ensure compliance of projects according to design document and various other requirements like Equal Employment Opportunity (EEO), Disabled Business Enterprise (DBE), labor wage rate, etc. by conducting interviews in the field,

- Generate payment estimates and make payments to the contractors,
- Note any possible disputes and notify the main office of notice of a claim,
- Monitor the available funding for the project so that there would be sufficient funds when approving any change orders,
- Notify the FHWA of change orders of more than $100,000 with the conditions.

Duties mentioned above are either related to DWR data collection or require DWR data. For example, the level of staffing required for a given type and size of a project can be determined based on similar projects conducted in the past. Approving change orders requires the review of works done so far (which is documented in DWR) and design documents. Thus, proper recording and storage of DWR data and any relevant documents becomes important.

Iowa DOT's Project Documentation Guideline (2004) states that project records must be maintained properly, all source documentations must be preserved, relevant electronic files must be backed up, and all the documentation must be stored so that it would be readily available when needed. It further states that DWR data should be factual, concise, complete, and legible. Diary entries should be made at the end of the day but no later than the following day.

Iowa DOT (2004) recommends that the following data regarding construction activities performed each day should be recorded:

- Date and weather conditions (sunrise, sunset, high temperature, low temperature, weather (sunny, rain, etc.) ;
- Contractors and subcontractors working;
- Construction work in progress;
- The substance of important conversations with the Contractor regarding
  - schedule,
  - changes authorized or substitutions allowed,
  - extra work order agreements,
  - interpretations of specifications,
  - identification of work deficiencies,
  - request for information,
  - schedules for future operations, or
  - other important details;
- Specialized equipment or procedures used;
- Comments on corrective measures taken;
- Names of visitors;
- Vehicle crashes;
- Significant discussions with property owners.

It further states that, sufficient details should be recorded so that important events can be reconstructed later as they actually occurred. And if there are any additional data that may be useful to determine appropriate compensation for claims or disputes, those data should also be recorded.

California Department of Transportation (Caltrans) provides similar instructions to their RCEs (Caltrans 2013a). It states that the Resident Engineer's DWR should include the information regarding the important discussions and agreements with the contractor, general statement about the type of work done, weather conditions, etc. (Caltrans 2013a). It further states that the Assistant Resident Engineer's DWR should include information such as location of work, brief description of the work performed, quantities placed and work completed, and significant statements by the contractor.

To record the progress of work in terms of quantities of work done, Iowa DOT uses five different methods (IaDOT 2004). The first one is *measured quantity*, in which the amount of work is measured directly or through tickets with direct measurements. The second one is called *computed quantity*, in which quantities are calculated from stations, length, etc. In *plan quantity*, no field measurements are performed and quantities from plans are used directly. In *lump sum*, no measurement is performed—instead, quantities are estimated visually for progress payment. Finally, some items are measured by *counts* and are counted in field.

Similarly, to inspect the quality of work and material, Iowa DOT has eight different methods: certification of compliance, approved brand, approved shop drawing & approved catalog cut, test report by an approved inspection agency, visual approval, approved source, lot acceptance, and fabrication report (IaDOT 2004).

2.3 Applications and Benefits of DWR Data Based on Literature

The DWR is the most important record kept by the inspectors (ALDOT 2013). An extensive amount of data is collected regarding general site conditions, work activities, resource details, and other remarks, which can be used for various applications and benefits as presented below.

2.3.1 Progress Monitoring and contractor payment

DWR data can be used to monitor project performances and progress in terms of site conditions, progress tracking, resource tracking, and inventory tracking (Cox, Perdomo, and Thabet 2002; Navarrete 1999). For example, the quantity of work done every day can be added together to generate total amount of work done. This can then be used to calculate an appropriate amount of payment to the contractors.

2.3.2 Claim and Dispute Resolution

Construction claims and disputes are prevalent in the construction industry (Yates and Epstein 2006). As such, many state DOTs focus their effort on collecting various DWR data in order to use them for dispute resolution. For example, Alabama DOT (2013) instructs the field personnel to collect the data "with the thought in mind that it may someday be a legal instrument that will substantiate a just claim or disprove an unjust one." Most of the time, the linguistic data recorded in the DWR system are the ones that become useful for the claims and dispute resolution.

Ellis and Thomas (2001) presented methodologies to evaluate delays in order to compensate contractors' claims. Such process of claim settlement needs various resources data from the field that are recorded in the DWR system.

As one state DOT representative said, 90% of the DWR data are not used unless there is a dispute. However, all data needs to be collected, as the 10% of the data becomes the vital piece to resolve those issues. But, those linguistic data are harder to analyze and automate. Such analysis is even more challenging when paper-based DWR systems are used. This necessitates collecting more structured data.

2.3.3 Production Rate Estimation and Contract Time Determination

McCrary et al. (2007) used DWR data from Louisiana DOT projects to estimate the production rates of various activities and developed a template based system to estimate the contract time for future projects. Woldesenbet (2012) also developed a DWR based production rate estimation system based on the data from Oklahoma DOT.

2.3.4 Weather Effect on Contract Duration

Researchers have used DWR data to quantify the impact of weather on construction productivity and schedule (Apipattanavis et al. 2010; Apipattanavis et al. 2010; El-Rayes and Moselhi 2001; Kenner et al. 1998; Nguyen et al. 2010; Shahin, AbouRizk, and Mohamed 2011; Woods 2008). Such studies have started with the simpler objective of determining the number of working days in a month. Later the studies were focused on quantifying the effect of weather events on specific activities as well as developing models to predict the effect of the weather on total duration of the projects.

2.4 Evolution of DWR Systems

DWR systems have evolved from paper-based forms to electronic systems. The electronic revolution in construction documentation started as early as 1968—when mainframe computers used to cost thousands of dollars. The electronic revolution then enabled the development of electronic DWR systems that are widely used by state DOTs in current time.

Woldesenbet et al. (2014) classified the information systems into three tiers, or generations, and applied the concept to DWR data. In the first generation, paper-based DWR system is used where expert judgment is used for decision making. In the second generation, semi-automatic data collection methods are used to store data in databases and data warehouses. In this generation, the information generated from the analyses of data using statistical analyses is used to make decisions. The third or ideal generation uses automated data collection methods and uses a knowledge portal system for the knowledge generated from the information. It uses a knowledge discovery approach for decision making. Many state DOTs were categorized as being in a transitional phase from the first to second generation of data generation. The evolution of DWR systems from paper-based to electronic versions are presented in this section.

2.4.1 Paper-based DWR Systems

DWR data has traditionally been collected and stored in paper-based media (Cox, Perdomo, and Thabet 2002). The traditional paper-based DWR forms included preprinted forms with data recording sections such as date, weather, work accomplished to that date, labor expended for that day, changes originated that day, delays, and strikes (ASCE Task Committee on Application of Small Computers in Construction of the Construction Division 1985).

Caltrans uses the CEM - 4601 form to collect DWR data. One aspect of the Caltrans form was notable. While electronic DWR systems used by various state DOTs were found not to have a functionality to record activity level resources data (except for force account), Caltrans' DWR form does have a function to record that data. A sample DWR form used by Caltrans is presented in Figure 2.1.

STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

ASSISTANT RESIDENT ENGINEER'S DAILY REPORT

CEM 4601 (REV 4/1999) CT# 7541-3504-6

JOB STAMP

Report No.

Date

S M T W T F S Circle Day

Shift Hours Start Stop

ASSISTANT RESIDENT ENGINEER'S DAILY REPORT

Location and Description of Operation

HOURS - ITEM NO.

WEATHER

EQUIPMENT AND LABOR:

EQUIPMENT NO.	NO. PERSONS	DESCRIPTION (Equipment or Labor)									IDLE OR DOWN	REMARKS (Reason for Idleness or other remarks)

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Figure 2.1 Paper-based DWR form system used by Caltrans (Source: Caltrans (1999))

A list of data attributes that can be collected in that DWR form is presented in Table 2.2.

Table 2.2 DWR data categories and data attributes that can be recorded in Caltrans DWR form CEM - 4601

Data category	Data attributes	Data type
General information	Report no.	Character
	Date	Numeric: ordinal
	Day	Character
	Shift hour start	Numeric: ordinal
	Shift hour stop	Numeric: ordinal
	Location and description of operation	Text
	Weather	Text
Equipment and labor	Item no.	Character
	Equipment no.	Numeric
	No. of persons	Numeric
	Description of equipment or labor	Text
	Remarks	Text
Others	Name	character
	Signature	-
	Title	character

Paper-based systems have their own challenges. For example, a four year project will have over 1,000 DWR forms, which makes it challenging to resolve any claims and disputes (ASCE Task Committee on Application of Small Computers in Construction of the Construction Division 1985). Dowd (2011) noted that the process of handling paper-based documents was inefficient and time consuming. Cox et al. (2002) noted that collecting DWR data in paper forms and storing them to a computer can save a vast amount of time compared to the traditional paper-based method only. As such, the development of an electronic DWR system started and is presented in next section.

2.4.2 Electronic DWR Systems

The benefits of using electronic DWR systems have been documented in multiple studies. McCullouch (1991), for example, estimated the annual saving of over two million dollars (as of 1991) for Indiana DOT when paperless processes are used. The estimated saving was based on savings of $60,000 on postage, $239,400 on paperwork processing, $1,742,260 on time saving, $37,000 on form printing and storage, $17,000 on permanent record storage, and $40,000 on management inquiries.

Some notable studies and documentations starting from the introduction of electronic systems in the construction industry to the development of currently used DWR systems are presented in Table 2.3.

Table 2.3 Evolution of digital DWR systems

Year	DWR System	Objectives and Features	Main distinction	Source
1968	California Contract Administration System (CAS)	Digital system for contract administration for mainframe systems.	Earliest electronic system	Caltrans (2010)
1988	Connecticut Construction Management and Reporting (CMR) System	Automation to deal with the problems of managing a large amount of construction activity data. Interactive terminal system for reporting, network capable.	Terminal based	McCullouch (1991)
1988	Michigan Construction Project Record Keeping Systems	Predecessor of FieldManager. Complete automation from construction site through contractor's payment by 1993.	-	E-mail
1991	Automated Construction Data Management System	Documentation of benefits of automation: to go paperless and make data easily accessible for analysis. Proposed features included: portable devices, Radio Frequency (RF) tags to track material hauled, barcode for testing samples, and electronic signature using card.	No application developed	McCullouch (1991)
1993	Computerized Daily Site Reporting	Up-to-date project information, faster response time in dealing with problems, documentation for transferring experiences from previous projects.	DWR specific application module	Russell (1993)
1993	Construction Field Data Acquisition with Pen-Based Computers	Reduce paperwork and get previously documented benefits such as complete and consistent data for better decision makings such as claim analyses, elimination of duplication of efforts, improved accessibility of data.	Touch-enabled portable devices	McCullouch & Gunn (1993) and McCullouch (1991)
1998	Vermont Maintenance Activity Tracking System (MATS)	Tracking employee's time spent, state and/or private equipment used, material used, and work accomplished.	Main focus on DWR data	Rogers (2013) and Spaulding (2000)
1998	Utah Project Development Business System	Electronically document the design, bidding, and construction of highway projects to save time and reduce data entry errors.	Integrated system	ExeVision (2012) and Utah DOT (2012b)
1999	Michigan FieldManager	Eliminate an error prone, slow and intensely manual DWR data collection process, standardize data collection throughout the state.	-	Michigan DOT (2005)
1999	AASHTOWare SiteManager (ASM)	Integrated series of computerized forms for entering and viewing all information needed for a contract from the planning stage to the archival stage.	Most widely used application as of now	AASHTO (1999)
1999	Pendragon Based Palm Application	Use of predefined lists and handwriting recognition methods for easier data collection.	Handwriting recognition	Navarrete (1999)
-	South Dakota Contract Management System	Assist the SDDOT personnel with managing construction measurement, payment, and material sampling and testing.	-	South Dakota DOT (2008)
1999	Kansas Contract Management System	Mainframe and standalone operations for pay estimates, material acceptance, etc.	-	Kansas DOT (1999)
-	Pennsylvania DOT (PennDOT) Next Generation (NeXtGen)	Documentation of construction data.	-	Penn DOT (2007)

Year	DWR System	Objectives and Features	Main distinction	Source
-	Minnesota Field Operations (FieldOps)	Recording data generated from field operations.	-	Minnesota DOT (2008)
2013	Adobe Air Based Android Application	Application for field data collection for field inventory and inspection.	Modern GUI, GPS, photo attachment	Blaesing-Thompson & Haubrich (2013)
2014	California Construction Management System	Replace the previous Contract Administration System (CAS) developed in 1968.	Under development	Caltrans (2010)

The Contract Administration System (CAS) developed by Caltrans in 1968 can be considered one of the earliest applications of a computerized system in state DOTs (Caltrans 2010). Later, in 1985, an ASCE Task Committee studied current and future applications of small computers in construction (ASCE Task Committee on Application of Small Computers in Construction of the Construction Division 1985). It identified DWR data as one of the data that can be collected using electronic systems. Similar to Caltrans, Connecticut DOT also developed a Construction Management and Reporting (CMR) system in 1988 to manage construction project data (McCullouch 1991). In 1988, Michigan DOT developed a Construction Project Recording System, which is a predecessor of a FieldManager system developed by the same DOT later.

Many studies were conducted by researchers in the 1990s to develop DWR systems. For example, McCullouch (1991) proposed an automated construction data management system with features to track materials using RFID and bar codes. Additionally, it proposed the use of electronic signatures using digital cards. Another study by Russell (1993) was entirely dedicated to the use of an electronic system for DWR data collection and reporting. Similarly, the concept of touch based systems for DWR data collection has been studied and experimented by McCullouch & Gunn (1993), which continued later in the 21st century (Cox, Perdomo, and Thabet 2002). The study by McCullouch & Gunn (1993) developed an application for pen based mobile devices for collecting field data such as time keeping and purchase orders. The study showed that the use of such devices did not directly save time on the site. But, later when data was used further for the analyses, time saving was realized in the office.

In late the 1990s, many state DOTs, including Vermont, Utah, Michigan, and Kansas DOTs, developed their own DWR systems. Vermont later collaborated with New Hampshire and Maine DOTs to complete the development of its Maintenance Activity Tracking System (MATS). Similarly, Michigan DOT's FieldManager was later developed further under the umbrella of AASHTO as AASHTOWare FieldManager (AFM).

After studying various DWR systems used by state DOTs, AASHTO developed a new DWR system called AASHTOWare SiteManager (then known as AASHTO Transport Site•Manager) in 1999, which is now the most popular DWR system in terms of the number of users (American Association of State Highway and Transportation Officials (AASHTO) 1999; Dowd 2011). As of 2014, state DOTs are still working on updating their current systems and developing new systems. For example, AASHTO releases minor updates every six months to its AASHTOWare products. And California, which developed one of the earliest construction management systems, has put forward a request for a proposal to develop a DWR system as well as accompanying Contract Management System (Caltrans 2010). Those current DWR systems are compared in terms of their structured data collection capabilities later in this chapter (2.5 Electronic DWR Systems Used by State DOTs).

While the collection of DWR data in field on paper and then storing the data in a computer can save a vast amount of time compared to the traditional Paper-based Only (PBO) method, it still requires double manipulation of data, which increases the possibility of typographical errors, inconsistencies in information, and the loss of information (Cox, Perdomo, and Thabet 2002). Cox et al. (2002) developed a Pocket PC based DWR system that can be used in site directly to collect DWR data. The data can then be transferred to an office computer for further use. As the data is transferred digitally, there is no possibility of errors in data due to double manipulation. As such, the process would also improve efficiency by saving time and improving communication.

2.4.3 Benefits of Electronic DWR System Over Paper-based DWR Systems

The benefits of using electronic DWR systems over paper-based DWR systems are pointed out in various studies (Russell 1993; Rogers 2013; Michigan DOT 2005; Fowler 2010). Michigan DOT, for example, reported cost saving of $22 million by automating the previously paper-based, error prone, slow, and intensively manual process of DWR data collection, material tracking, and contractor payment using their DWR system called FieldManager (FM) (Michigan DOT 2005). Some of the benefits of the electronic DWR systems over paper-based DWR systems are:

- Reduced time and effort for DWR data entry, transfer, and retrieval (see for example a time saving of about 20 hours on each time sheet data entry by using MATS (Rogers 2013)),
- Faster response time to the problems as information is available on time (see for example the possibility of faster response to problems such as claims because of the integrated systems (Russell 1993)),
- Possibility of integrated data analyses (see for example integration of DWR data with project planning and scheduling (Russell 1993)),
- Reduce costs (see for example Vermont, New Hampshire, and Maine that reported the payback of the system development costs in 2 years which indicates savings afterwards (Fowler 2010)),
- Increased schedule certainty (see for example increase in schedule certainty because of quick update of current schedules (Russell 1993)),
- Increased accuracy of data as a result of direct data collection in site rather than noting it down from memory later (Rogers 2013; Russell 1993)),
- Improved communication (Rogers 2013),
- Reduction in papers (Rogers 2013).

2.5 Electronic DWR Systems Used by State DOTs

Three electronic DWR systems were found to be developed, maintained, and used by common efforts from more than one state DOT. Those systems are AASHTOWare SiteManager (ASM), AASHTOWare FieldManager (AFM), and Maintaining Assets for Transportation Systems (MATS). A screenshot of ASM is provided in Figure 2.2 to visually present typical data attributes that can be recorded in electronic DWR systems.

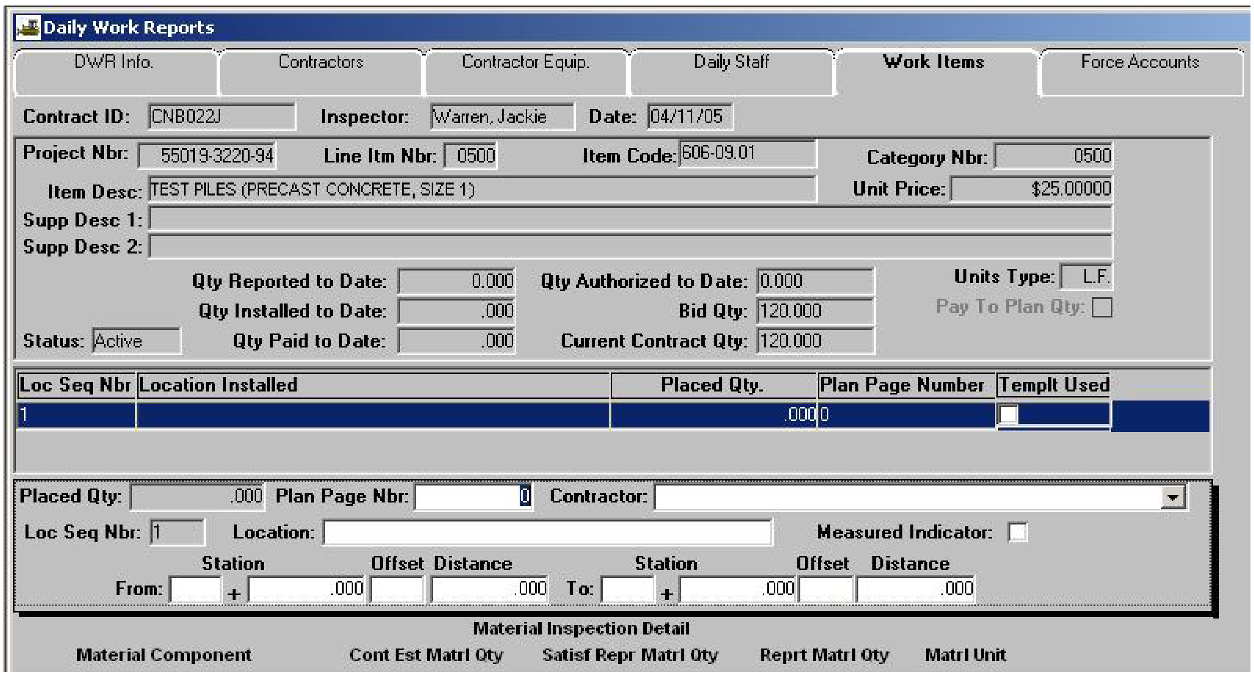


Figure 2.2 AASHTOWare SiteManager (ASM) screenshot (Source: (2011))

Seven State Specific Systems (SSSs) developed for DWR data collection and analyses by Pennsylvania, Utah, Delaware, Minnesota, Arizona, South Dakota, and Kansas DOTs were also identified and reviewed for this study. DWR data attributes that can be collected by those DWR systems are presented in Table 2.4 based on the review of literature of corresponding systems (Cambridge Symantics, Inc. et al. 2011; Couto 2005; DelDOT 2007; Fowler 2010; Homberg and Gallegos 2007; Kansas DOT 2013; MnDOT 2008; NHDOT 2014; PennDOT 2007; Rogers 2013; SDDOT 2008; TDOT 2011; Tibbits 2007; US DOT 2014; UDOT 2006; UDOT 2012a).

Table 2.4 Data Attributes that can be collected in DWR systems used by state DOTs

Attributes	ASM	MATS	AFM	CDS NeXtGen	PDBS Field Book	FDC	FieldOps	Pen	CM&P	KCMS
General										
Date	X	X	X	X	X	X	X	X	X	X
Day charging	X	-	X	-	X	-	X	-	-	X
Weather	-	-	X	-	X	X	-	X	-	-
Weather by time	-	-	-	-	-	-	-	-	-	-
AM weather	X	-	-	X	-	-	-	-	-	-
PM weather	X	-	-	X	-	-	-	-	-	-
Low temperature	X	-	X	X	X	-	-	-	-	-
High temperature	X	-	X	X	X	-	-	-	-	-
Temperature by time	-	-	-	-	-	X	-	-	-	-
Sunset	-	-	X	-	-	-	-	-	-	-
Sunrise	-	-	X	-	-	-	-	-	-	-
Work status	-	-		-	X	-	-	X	-	-
Work suspended from	X	-	-	-	-	-	X	-	-	-
Work suspended to	X	-	-	-	-	-	X	-	-	-
Accident indicator	-	X	-	-	-	-	-	-	-	-
Work activities										
Location	X	X	X	X	-	X	-	X	X	-
Installation station	-	-	-	-	-	X	X	-	-	-
Installation station from	X	X	X	X	X	-	-	-	-	-
Installation start town	-	X		-	-	-	-	-	-	-
Installation station to	X	X	X	X	X	-	-	-	-	-
Installation end town	-	X	-	-	-	-	-	-	-	-
Offset	-	X	-	-	-	-	-	-	-	-
Route direction		X	-	X	-	-	-	-	-	-
Item	X	X	X	X	X	X	X	X	X	X
Installed item quantity	X	X	X	X	X	X	X	X	X	X
Item measurement indicator	X	-	-	-	-	-	-	-	-	-
Controlling item indicator	X	-	X	-	-	-	X	-	-	-

Attributes	ASM	MATS	AFM	CDS NeXtGen	PDBS Field Book	FDC	FieldOps	Pen	CM&P	KCMS
Item needs attention flag	-	-	X	-	-	-	-	-	-	-
Item completion status	-	-	X	-	X	-	-	-	-	-
Material stockpile										
Stockpile quantity	-	-	X	-	-	-	X	X	-	X
Material source	-	-	X	-	-	X	-	X	-	-
Material manufacturer	-	-	-	-	-	-	-	X	-	-
Audit/approval status	X	-	-	-	-	-	X	X	-	-
Contractor details										
Contractor	X	-	X	X	X	X	-	-	-	-
Contractor presence	X	-	-	-	-	-	-	-	-	-
Daily staff presence	X	-	-	-	-	-	-	-	-	-
Contractor working status	-	-	X	-	-	-	-	-	-	-
Contractor hours worked	-	-	X	X	-	X	X	-	-	-
Labor details										
Personnel type	X	-	X	X	X	X	-	X	-	-
Personnel number	X	-	X	X	X	-	-	X	-	-
Personnel hours	X	-	X	-	X	-	-	X	-	-
Equipment details										
Equipment type	X	-	X	X	X	X	-	-	-	-
Equipment number	-	-	X	X	-	-	-	-	-	-
Equipment hours	X	-	X	-	X	-	-	-	-	-
Equipment standby hours	-	-	-	-	X	X	-	-	-	-
Utility details										
Utility personnel type	-	-	-	-	-	X	-	-	-	-
Utility equipment type	-	-	-	-	-	X	-	-	-	-
Utility equipment standby time	-	-	-	-	-	X	-	-	-	-
					-	-	-	-	-	-
DOT staff/inspector	X	X	X	-	-	X	-	-	X	-
DOT staff hours	-	X	-	-	-	-	-	-	-	-
DOT staff time from	-	-	-	-	-	X	-	-	-	-

Attributes	ASM	MATS	AFM	CDS NeXtGen	PDBS Field Book	FDC	FieldOps	Pen	CM&P	KCMS
DOT staff time to	-	-	-	-	-	X	-	-	-	-
DOT resources										
Vehicle mileage	X	-	-	X	-	-	-	-	-	-
DOT/Rental equipment	-	X	-	X	-	-	-	-	-	-
DOT/Rental equipment hours	-	X	-	-	-	-	-	-	-	-
DOT/Rental equipment mileage	-	-	-	X	-	-	-	-	-	-
Miscellaneous										
Force account details	X	-	-	X	-	-	-	X	-	-
Visitors	-	-	-	-	X	X	-	-	-	-

The data attributes noted in the table are focused on categorical (interval, nominal, and ordinal) and numerical data attributes rather than linguistic data. All the systems reviewed have a function for the collection of linguistic remarks in addition to the data attributes presented in the table. Some of the linguistic remarks that can be recorded in those DWR systems include:

- Instructions given to contractors,
- Unusual weather conditions,
- Causes of delays,
- Safety incident details,
- Explanations regarding work suspension,
- Equal Employment Opportunity (EEO) and Wage rate verification.

Overall, the systems maintained by multiple state DOTs were found to have better structured data attribute collection capability compared to SSSs maintained by single state DOTs. Many state DOT systems are capable of collecting essential data attributes, such as DWR date, temperature, weather, day charging, quantity of item installed, location of the item installation, contractor working along with their equipment and personnel detail, and stockpile materials. Some systems track the total hours contractors worked in a given day while others track the labor hours and equipment hours separately. Similarly, some systems allow for the tracking of the hours spent by DOT personnel for supervising the projects and standby times of equipment in addition to running time. Some of the notable points regarding the DWR systems are presented in Table 2.5. ASM and AFM were considered to be well integrated to other systems as AASHTO have developed a number of other systems with a bigger vision of an integrated system. Similarly, PDBS and MATS have similar visions of integrated system development. Utah have a number of systems within PDBS which can exchange data from one system to another. And, MATS, as the name suggests, is integrated into asset management system and can also interact with several other systems like financial system, payroll system, etc. (Cambridge Systematics, Inc., EVS, Inc., and Markow 2011).

Table 2.5 Features of DWR systems used by state DOTs

DWR System	Structured data attributes	Integration with other systems	Remarks
ASM	Very comprehensive	Well integrated	- powerful templates to collect additional data attributes - powerful templates to generate additional reports - web-based version under development
MATS	Average	Well integrated	- partnership between tri-states Vermont, New Hampshire, and Maine - enables side by side performance comparison of the three states - type, filter, and search functionality to go through long lists of items - integrated with GIS mapping feature
AFM	Very comprehensive	-	- originally developed by Michigan DOT - attention flag to indicate items that needs attention
CDS NeXtGen	Comprehensive	-	- location wise quantity data collection
PDBS Field Book	Comprehensive	Well integrated	- companion mobile system in past
FDC	Comprehensive	-	- capable of collecting multiple weather and temperature data by time
FieldOps	Average	-	- built in quantity calculator
Pen	Average	-	- uses existing login information of DOT employees - text formatting option for linguistic remarks - dairy search functionality
CM&P	Minimal	-	-
KCMS	Minimal	-	-

The systems reviewed have varying reporting capabilities. Some of the reporting capabilities noted from the literature are:

- Item level progress details in terms of dollar amount and quantity,
- Remaining stockpile,
- Total working days charged,
- Percentage of working days used,
- Time extensions,
- Estimated payments for the work done to the date,
- Percentage of total contract amount,

- Progress report of statewide contracts,
- Material overrun/underrun.

In addition to the systems presented above, Caltrans is also in the process of developing a new construction management system including a DWR module to replace its older system (Caltrans 2010).

2.6 Commercial Off-The-Shelf (COTS) Systems

A number of Commercial Off-The-Shelf (COTS) systems for DWR data collection were also reviewed as a part of this study. A COTS product is usually tailored for specific users and made available to the general public (Janssen 2015). The study identified nine such systems, which are listed below (*8 Minute Constructware Demo* 2010; HCSS 2013; Integral Vision 2011; Trimble Navigation Limited 2014a; Trimble Navigation Limited 2014b):

- HCSS Heavy Job,
- Integral Vision PMIV Daily Diary,
- Trimbler Proliance Field Management,
- ViewPoint Construction,
- Autodesk Constructware,
- Trimble Prolog Manager Field Administration,
- Field Automated Communication Systems (FACS),
- Timberline Gold Collection, and
- Bear River Associates ePeg.

Most of those systems were tailored for contractors and were not very suitable for state DOTs. Overall, those systems have more detailed data collection regarding the resources being used compared to the systems used by state DOTs. At the same time, other aspects of DWR data collection (such as weather and site conditions) are more linguistic in majority of the systems. The first four systems are compared in Table 2.6.

Table 2.6 Comparison of COTS Systems for DWR

Item	HCSS Heavy Job	Integral Vision PMIV Daily Diary	Timbler Proliance Field Manager	Trimble Prolog Manager Field Administration
Site conditions	X	X	X	X
Weather conditions	-	X	X	X
Work tracking	X	X	-	X
Material tracking	-	X	-	X
Labor tracking	X	X	X	X
Equipment tracking	X	X	X	X
Attachments	X	-	-	-
System type	Desktop	Web	Web	Desktop
Client	Contractor	Contractor and owner	Contractor	Contractor

One notable feature about the COTS systems is the data visualization techniques implemented in the systems. Figure 2.3 shows a sample data visualization technique that is implemented in Trimble Proliance Field Management. No such efforts were noted in the state DOT developed DWR systems.

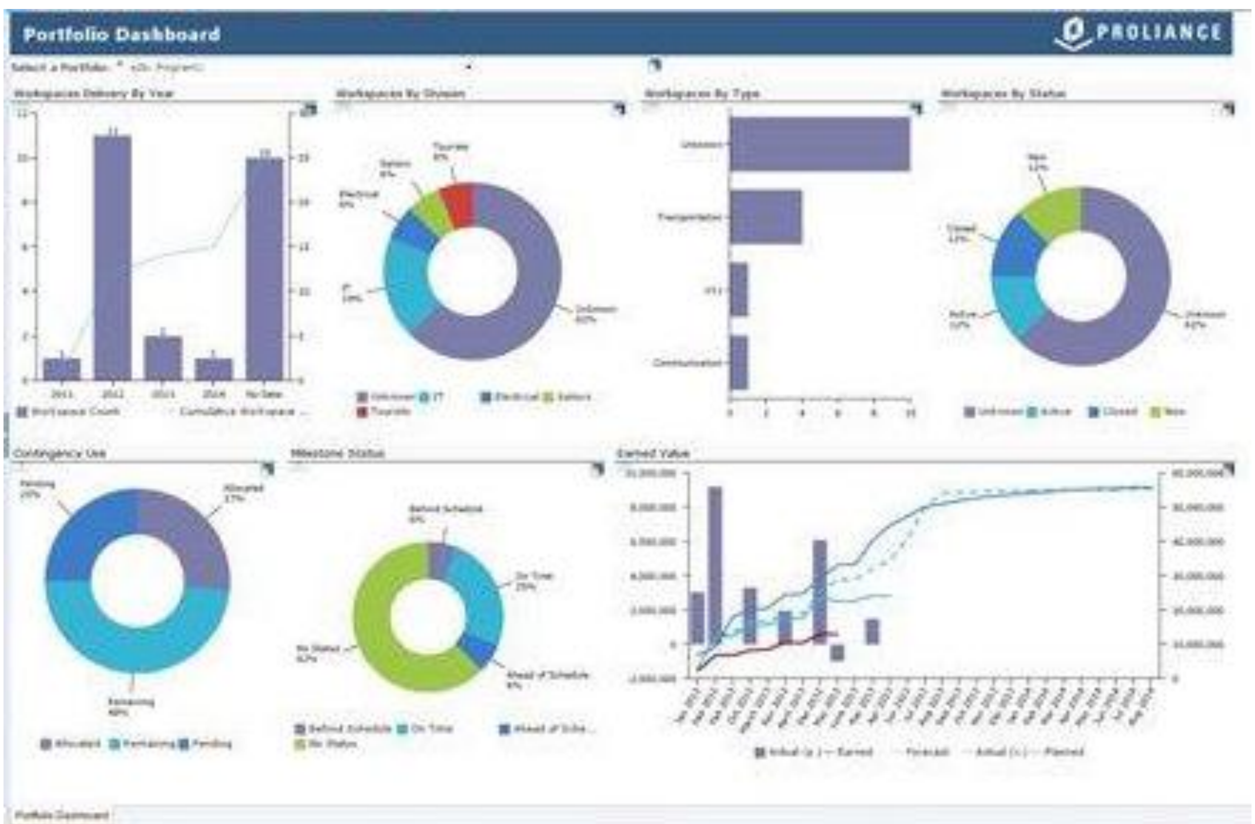


Figure 2.3 Trimble Proliance Analytics (Source: Trimble Navigation Limited (2014c))

3 RESEARCH METHODOLOGY

The study consists of eight tasks as presented in Figure 3.1. The main objective of the study is to increase DWR data utilization in state DOTs by developing an advanced comprehensive framework for developing a DWR system that can be used for automating various analyses based on the DWR data. The study consists of an extensive literature review, questionnaire surveys, and interviews. The results of those tasks are then used to identify the applications of the DWR data, a data model suitable for those applications, and the development of a comprehensive advanced DWR framework. The framework developed is evaluated by seven DWR experts in the U.S. Finally, the conclusions and recommendations are provided based on the findings of the study. The details of the methodologies are provided in five major subsections below.

3.1 Literature Review

The literature review for this study consists of an extensive review of literature related to various applications of DWR data, various analyses based on DWR data, the use of DWR data for various user groups or teams within state DOTs, and state DOT manuals regarding the collection and use of various DWR data in their DWR systems.

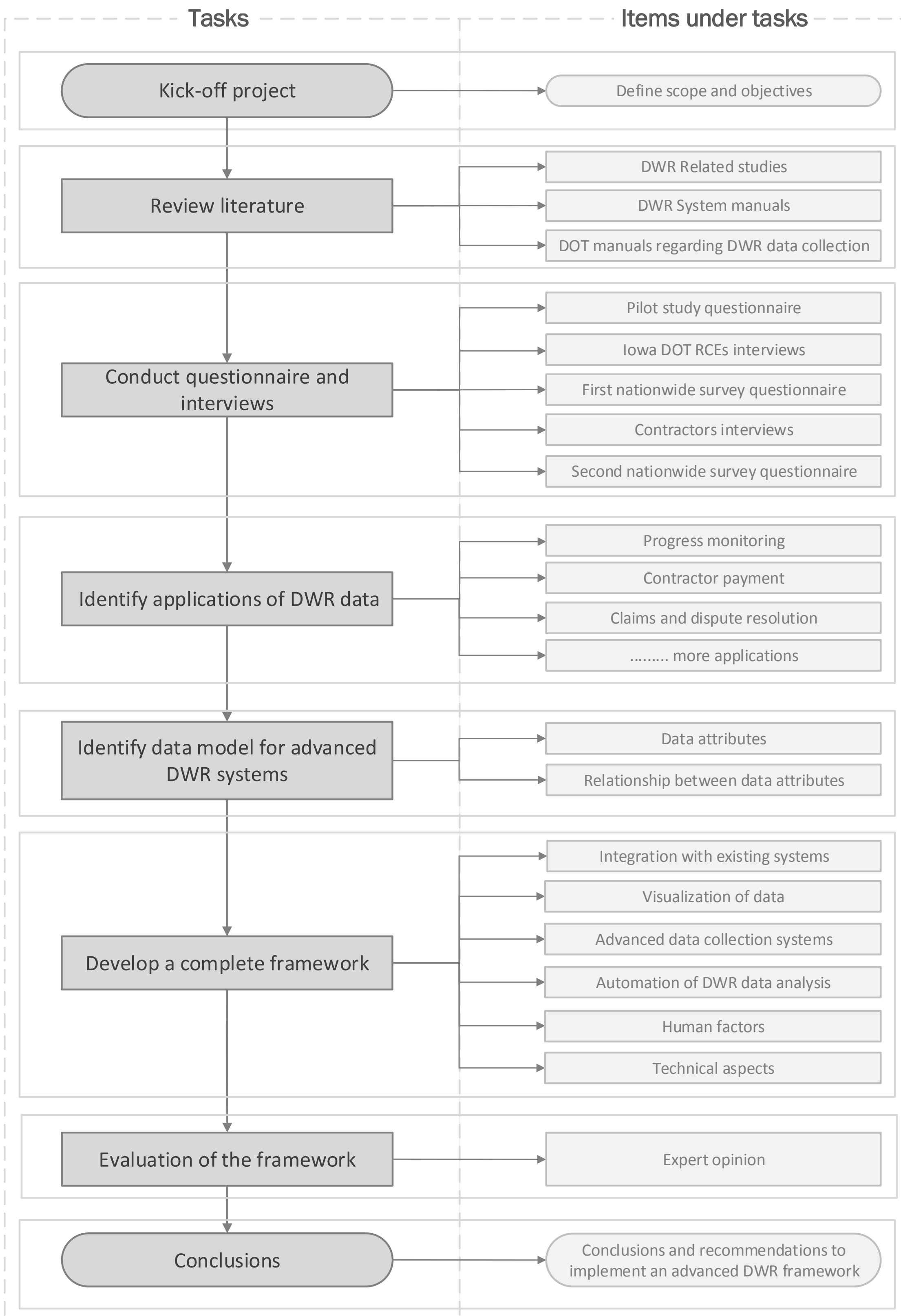


Figure 3.1 Research methodology

3.2 Iowa DOT RCEs' Interviews

Five Iowa DOT RCEs are interviewed to understand the current practices of collecting and utilizing DWR data. The interviewees are given an interview guideline a couple of days before the interview to give them some time to obtain relevant materials and be better prepared for answering the questions. The major items studied via interviews are:

- Current DWR system used by Iowa DOT,
- Staff responsible for collecting the DWR data,
- Types of data collected,
- Current utilization of DWR data,
- Various decisions that can be made from DWR data,
- Challenges for collecting and utilizing DWR data.

3.3 Nationwide Questionnaire Surveys

There are two nationwide questionnaire surveys conducted for this study. The first questionnaire is based on the findings from the literature review and Iowa DOT RCEs' interviews. The second questionnaire is based on the additional findings from the first questionnaire.

3.3.1 First Survey

The first questionnaire is prepared to synthesize the current practices of using DWR systems in state DOTs. The questionnaire consists of 8 questions, and its objectives are similar to that of the Iowa DOT RCEs' phone interviews. The questionnaire is focused on the following aspects of the DWR systems:

- Current DWR systems used by state DOTs (including electronic systems and paper-based systems),
- Availability of manuals for those DWR systems to study its functionalities in detail,
- Current benefits obtained by using DWR data,
- Importance of the benefits obtained by using DWR data,
- Challenges faced by state DOTs to better utilize DWR data.

Efforts are made to limit the number of questions as well as the number of open ended questions. A study has shown that close ended questions yield a higher response rate as it takes less time to complete (Reja et al. 2003). In addition, analyses of close ended questions are more straightforward than the analyses of open ended questions. The questionnaire is developed in a web-based system called Qualtrics. The results are analyzed qualitatively and quantitatively.

3.3.2 Second Survey

The second national survey questionnaire is conducted with the objectives of understanding the current level of automation in various benefits that can be obtained from the DWR data. Additionally, it seeks to identify the gap between the potential benefiting user groups or teams within state DOTs and the currently benefiting user groups or teams. The questionnaire also seeks feedback from the state DOT representatives regarding several new components or features to existing DWR systems. Additionally, it tries to quantify extra efforts required to collect additional detailed DWR data.

3.4 Contractors' Phone Interviews

Two contractors' supervisors are contacted via e-mail and interviewed via phone to understand their perspectives and practices of collecting DWR data. Interview guidelines (Appendix D) were sent to the interviewees several days before the interview to allow them to better prepare for the interview. The interview focused on understanding the various data attributes collected by the contractors, its current applications for their businesses, and the DWR systems used by the contractors.

3.5 Framework Development

Based on the literature review, interviews, and questionnaire surveys, an ideal framework is developed for an advanced DWR system. The framework is developed by the qualitative and quantitative analysis of the surveys, and the critical review of current DWR systems and existing literature.

3.6 Validation of the Framework

The framework is validated by seven DWR experts in the U.S. The validation process focuses on evaluating the level of advancement provided by the framework to update existing DWR systems and develop a new DWR system, as well as evaluating the comprehensiveness of the framework and ease of comprehension. The survey questionnaire used for the validation is presented in Appendix F.

3.7 Conclusions and Recommendations

Based on the findings of the study, conclusions and recommendations are provided for the state DOTs regarding the use of the advanced framework for data-driven decision making and improvements that can be made to the system and business practices.

4 NATIONWIDE QUESTIONNAIRE SURVEY AND IOWA DOT RCES' INTERVIEW RESULTS

This chapter presents the results of two nationwide questionnaire surveys conducted to understand the current practices of collecting DWR data, the level of details being collected in DWR systems, utilizing the DWR data for various applications, and the limitations of various DWR systems being used by the state DOTs. This chapter also presents the results of the interviews conducted with the Iowa DOT Residential Construction Engineers (RCEs) and two contractors' supervisors. The results are provided in chronological order—results from the Iowa DOT RCEs' interviews are provided first, followed by the results of the first national questionnaire survey, results of the contractors' supervisor interviews, and finally the results from the second national questionnaire.

4.1 Iowa DOT RCEs' Interviews

Four Iowa DOT RCEs were interviewed to understand the current practices in Iowa DOT for collecting, storing, and analyzing DWR data. The guideline used for the interviews is provided in Appendix A. The current practices followed by the major findings are presented in following sections.

4.1.1 Current Practices of Collecting, Storing, and Analyzing DWR Data in Iowa DOT

Iowa DOT inspectors and RCEs first import a base file containing the project information and bid items from AASHTOWare FieldManager (AFM) installed in the office computer to AASHTOWare FieldBook (AFB) installed in the field computer. Then inspectors and RCEs collect various DWR data including quantities of work done, day charging, weather data, etc. in AFB. Quantities for major pay-items are collected by physical measurement while other items are reported by visual approximation. It was noted that while some inspectors collect the labor data, others do not. Safety related data are collected in linguistic format unless there is an incident, in which case a separate incident related form is used to collect more detailed data. Contractor performance data is also recorded in a separate form by the inspectors, which is then signed and approved by RCEs. Quality control data is provided by the contractors and tests on smaller samples are also provided by the inspectors. The test results from contractors are overwritten with the results from the inspectors, if those are different. Those quality control data are recorded separately in AFM. In AASHTOWare SiteManager (ASM)—another DWR system that is used by other state DOTs—those quality control data can be recorded within the system.

Once the data is collected in the AFB, it is then exported to AFM using a flash drive or e-mail. After the data is exported in the AFM, updated data is exported back to AFB and previously recorded data are restricted from being modified in AFB. Some reports are then generated and sent to the central office every two weeks and include information such as summary of quantities, payments, etc.

The RCEs interviewed noted that the workload has been increasing over time because of the decreasing size of the workforce in the DOT. To make the best use of the available resources, inspectors and RCEs spend only a few hours a day for smaller projects with about 20 pay items. Sometimes they have to concurrently monitor the projects, which are located as far as 20 miles away, every day. In case of larger projects with multiple subcontractors that have hundreds of pay items, there may be five to six inspectors in the same site. One RCE noted that there are 9 inspectors and about 70 projects running at that time. RCEs questioned the need to collect more detailed DWR data (with the exception of safety related data) because of an already increasing workload. The same RCE noted that the increasing use of automated tools and better equipment has made it easier to do tasks more efficiently in lesser time than before.

Most contracts in Iowa DOT are based on working day contracts and some are based on calendar day. In case of the working day contracts, tracking the days being charged becomes very important data that is collected in the DWR system. Days may not be charged in case of adverse weather, utility issues, etc. The DOT tracks the working day used and percentage of work done as indicators for tracking the work progress. The day charging data becomes important also for charging liquated damages to the contractors, which ranges from $300 per day for small projects to $1500 per day for larger projects (IaDOT 2012).

A lot of time is spent in the site collecting DWR data—ranging from 8% of total time for paving projects to 30% time for bridge projects. Although a lot of data is collected in the field, one RCE noted that, 90% of the data will never be used. But, all data is collected because sometimes the 10% of the data becomes vital for the DOT for various reasons, like claims and disputes. If the process is automated, the DWR data collected in the site can be integrated with travelers' information websites to inform road users of the real-time work zone information. Additionally, the DWR data is important for office audits, material audits, and audits conducted by district construction staff members.

One RCE noted that there was an effort to develop their own DWR system in past but the effort was later halted. Another RCE noted the need of using DocExpress™ to exchange the documents and wanted an integrated system so that there is no need to switch back and forth between multiple systems. The challenge of utilizing linguistic remarks data among others were also noted by RCEs. Analysts have to go through them manually if such data are to be analyzed. The safety data can further be utilized for contractor evaluation if safety data analysis can be automated. There is no data visualization being implemented in the system for any purpose. Similarly, the challenge associated with location data collection when station markers are missing was also noted by one of the RCEs. Also, because of the lack of generating production rates programmatically, RCEs are using the production rates based on their past experience.

4.1.2 Findings from the Interviews

The major finding of the interview is the identification of various data attributes collected in their DWR system and its variation with the inspectors and RCEs, which can result in data quality issues. Additionally, it was noted that there is a lack of proper utilization of already collected DWR data. As a result, the RCEs depend on personal experience for information such as historical production rates. The challenges associated with the linguistic data collection were also noted from the interviews. Also, the lack of proper resources for collecting more detailed data was noted. Finally, some automated tools and equipment have made it easier to perform the RCEs tasks more efficiently than before.

4.2 First Nationwide Questionnaire Survey Results

The first questionnaire survey was conducted with the objective of identifying the current DWR systems being used by state DOTs, the importance of DWR data, the benefits of electronic DWR systems, and the challenges of utilizing DWR data. The questionnaire is provided in Appendix B. A pilot study was conducted from March 25 to April 2, 2014 with seven state DOT (Iowa, Nebraska, South Dakota, Minnesota, Indiana, Missouri, and Michigan) representatives before conducting the first nationwide questionnaire survey. Four responses (57.14% response rate) were received during the pilot survey questionnaire. After that, a nationwide questionnaire survey was conducted after making minor changes to the questionnaire prepared for the pilot questionnaire. The first nationwide questionnaire survey was conducted from April 9 to April 25 with 433 state DOT representatives, out of which 151 responses (34.87% response rate) were received. As there were no major changes in the questionnaire used for the pilot survey and the nationwide survey, responses from the two surveys were combined, analyzed, and presented in this section. Overall, the response rate of the survey was 35.23% (155 out of 440). In terms of the number of states, responses were received from 40 states out of 50, which represents an 80% response rate. The results of the survey are presented in the following sections.

4.2.1 Current DWR Systems Used by State DOTs

The 41 states that responded to the survey are presented graphically in Figure 4.1.

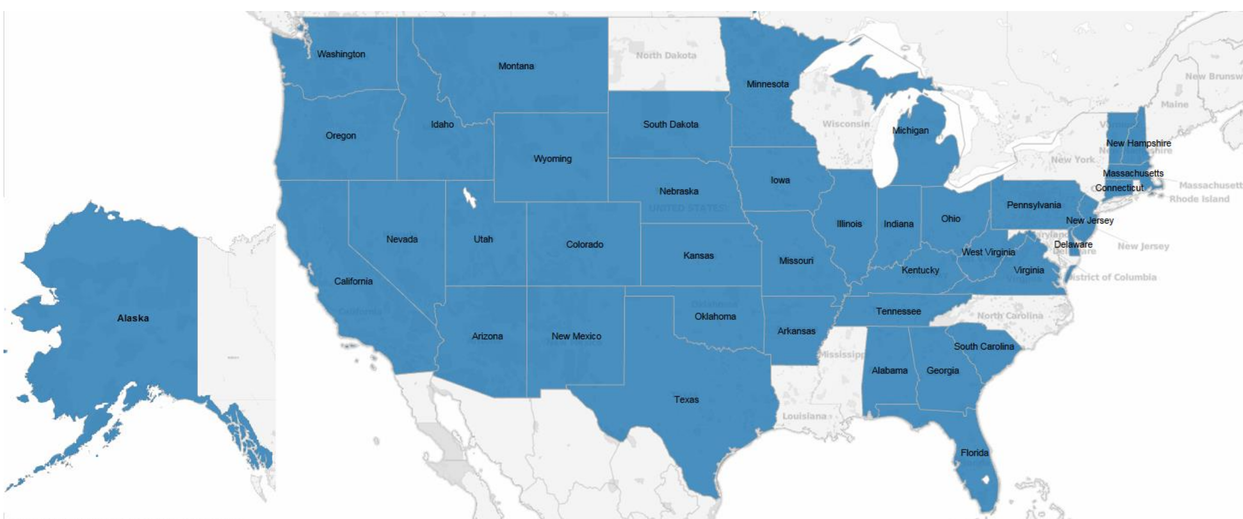


Figure 4.1 States that responded to First National Survey Questionnaire

The survey identified that there are three states (California, Massachusetts, and Nevada) that use paper-based DWR systems, 23 states that use electronic DWR systems along with paper-based DWR systems, and 14 states that have completely transferred over to electronic DWR systems

(Figure 4.2). It should be noted that there were different practices in different districts in the same office, i.e. some districts may use an electronic system only while other districts within the same state use a paper-based system or the combination of the paper-based and electronic systems. Those states are categorized as states using electronic DWR systems along with paper-based DWR systems.

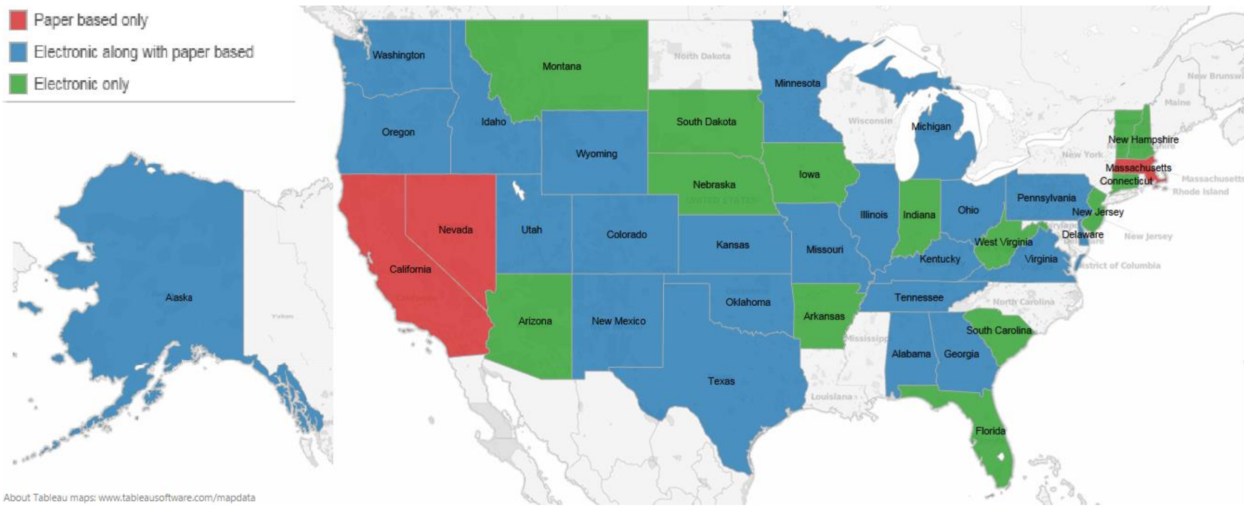


Figure 4.2 States utilizing the paper-based DWR systems to electronic DWR systems

Figure 4.3 presents more detailed classification of state DOTs by the type of DWR applications used. In the figure, the state DOTs that use the electronic DWR systems further use various systems that can be classified into Electronic Documentation Systems (EDSs), AASHTOWare SiteManager (ASM), Maintaining Assets for Transportation System (MATS), AASHTOWare FieldManager (AFM), and State-Specific Systems (SSSs). The PBO represents the state that uses "Paper-based Only" DWR systems.

Figure 4.3 DWR Systems used by state DOTs

Among the electronic DWR systems, ASM is the most popular system used by 22 states that responded to the survey. In terms of the number of respondents, ASM is used by 106 respondents (Figure 4.4). It may be noted that the total number of responses in Figure 4.4 is 216, which is higher than total number of respondents. It is because the categorizations are not mutually exclusive (e.g. respondents with ASM also use paper-based systems and counted in both categories).

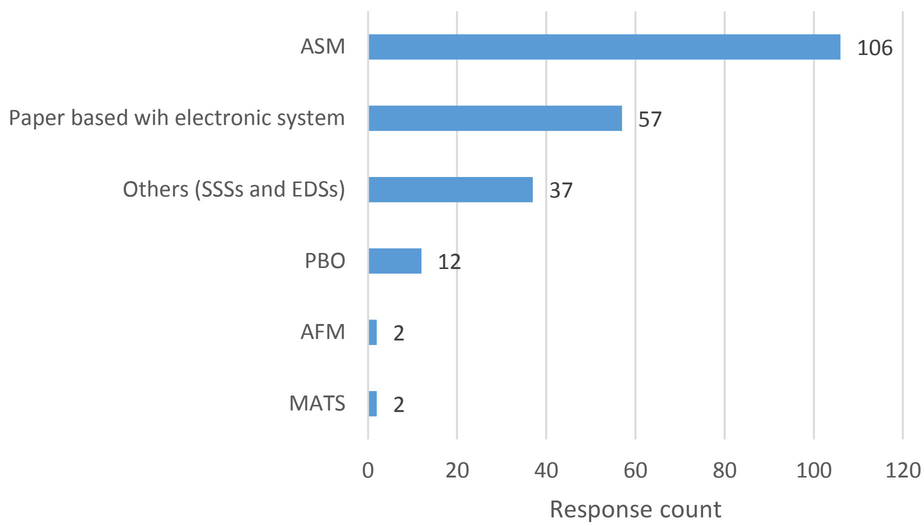


Figure 4.4 Number of respondents using various DWR systems

MATS is another popular DWR system, which was developed by the combined effort of Vermont, Maine, and New Hampshire DOTs, and has some state specific modifications. It may be noted that no response was received from Maine DOT but is presented in the figure. Finally, AFM is another system, which was originally developed by Michigan DOT and later developed further as AASHTOWare product. AFM was reported to be used by Michigan and Iowa DOT. Besides those systems shared by multiple DOTs, some state DOTs have developed in-house systems to record DWR, data which are listed below:

- PennDOT CDS NeXtGen,
- Utah Project Development Business System (PDBS),
- Delaware Field Data Collection DelFDC),
- Minnesota DOT Field Operations and TRACS,
- Arizona DOT Pen and maintenance database,
- South Dakota Construction Measurement & Payment System (CM&P),
- Kansas Construction Management System (KCMS),
- Illinois Construction Records System (ICORS),
- California Construction Management System (CCMS)—under development,
- Alabama DOT Construction and Material Management System (CAMMS)—under development.

In addition to various SSSs, some states reported the use of generic document sharing systems like SharePoint, as well as spreadsheets and access databases for collecting the DWR data. Those Electronic Documentation Systems (EDSs) can be considered transitional systems from PBO systems to digital DWR systems. The overview of the above mentioned DWR systems is presented in 2.

Out of 155 responses, 128 state DOT representatives stated that they maintain a historical database in a central database that can be readily accessed for various analyses (Figure 4.5).

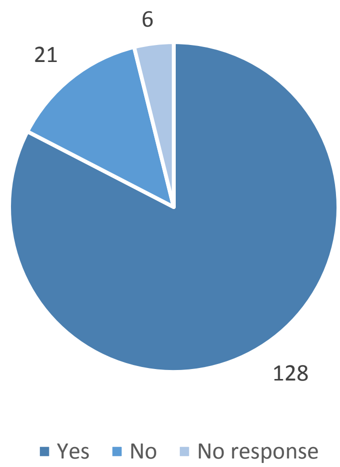


Figure 4.5 Central database for DWR data

Out of 58 respondents who reported that they do not use an electronic DWR system, 39 respondents indicated that they have plans to use an electronic DWR system in the near future (Figure 4.6). Note that the number of respondents who answered this question (58) was slightly different than the number of respondents that stated they use paper-based systems as one of their DWR data collection systems.

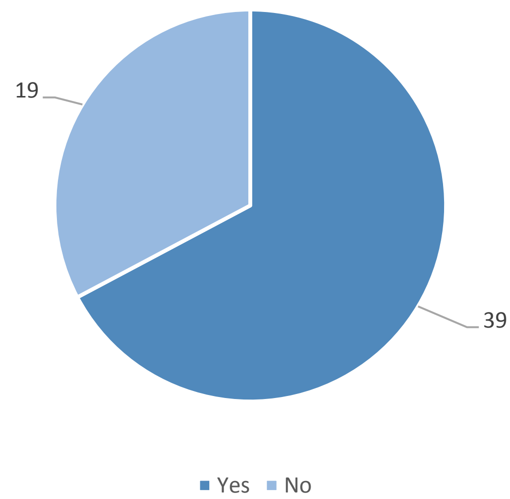


Figure 4.6 Planning for electronic application in near future

Also, 136 respondents stated that they have some form of manual regarding the DWR data collection criteria or use the DWR system (Figure 4.7).

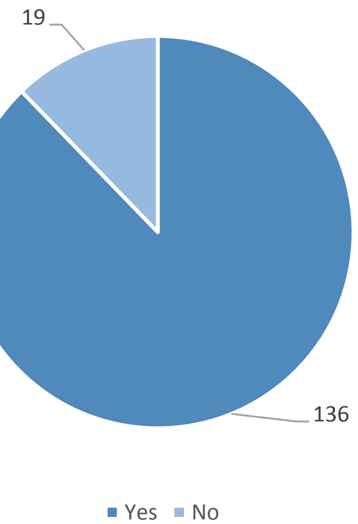


Figure 4.7 Availability of DWR data collection criteria or DWR system manual

4.2.2 Data Collected in Current DWR Systems

Eighteen different categories of DWR data attributes are identified based on the literature review. Respondents were asked if those data were collected in either their main electronic DWR system or in secondary DWR systems (paper-based forms). Figure 4.8 shows that most of the data are collected in their main system and some were collected in a secondary DWR system. Some of the representatives did not use any electronic DWR systems. As such, the question was not as relevant or clear to them as later realized. It can be assumed that those respondents assumed their paper-based system to be their main DWR system. Figure 4.9 shows the importance of the same data attributes as indicated by the average ratings provided by the respondents.

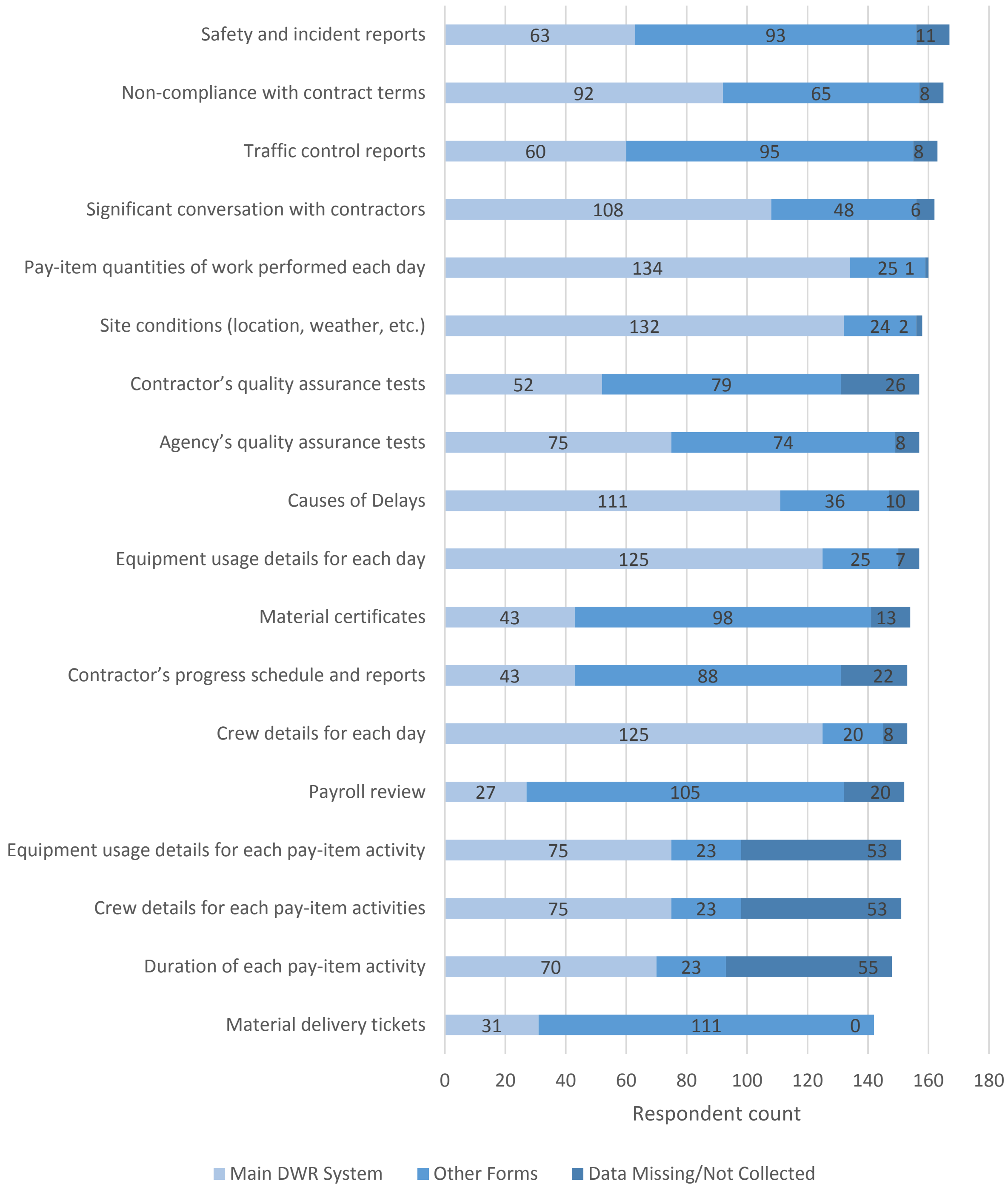


Figure 4.8 Data collected in current DWR systems

Figure 4.8 shows that most state DOTs collect pay-item quantities of work performed each day in their main DWR system as a way to keep track of the construction progress. Pay-item quantities of work performed each day is also noted as the most important data collected in the DWR system, as indicated by the average rating of 4.58 for the potential benefits of the data (Figure 4.9). As such, it can be concluded that the current primary purpose of DWR systems is the progress monitoring. All the DWR systems reviewed for the study have structured fields to collect the daily work quantities. Site conditions are also a very important aspect of the DWR data—especially for the work day charging and weather related delays. As such, most of the DWR systems also have a system to collect the site condition data. Similarly, the crew details and equipment details were also collected by the majority of the respondents in their main DWR system. It may be noted that while the DWR systems do have a function to collect the DWR data every day, state DOTs also practiced intermittent collection of the DWR data (see for example Florida DOT (2000)).

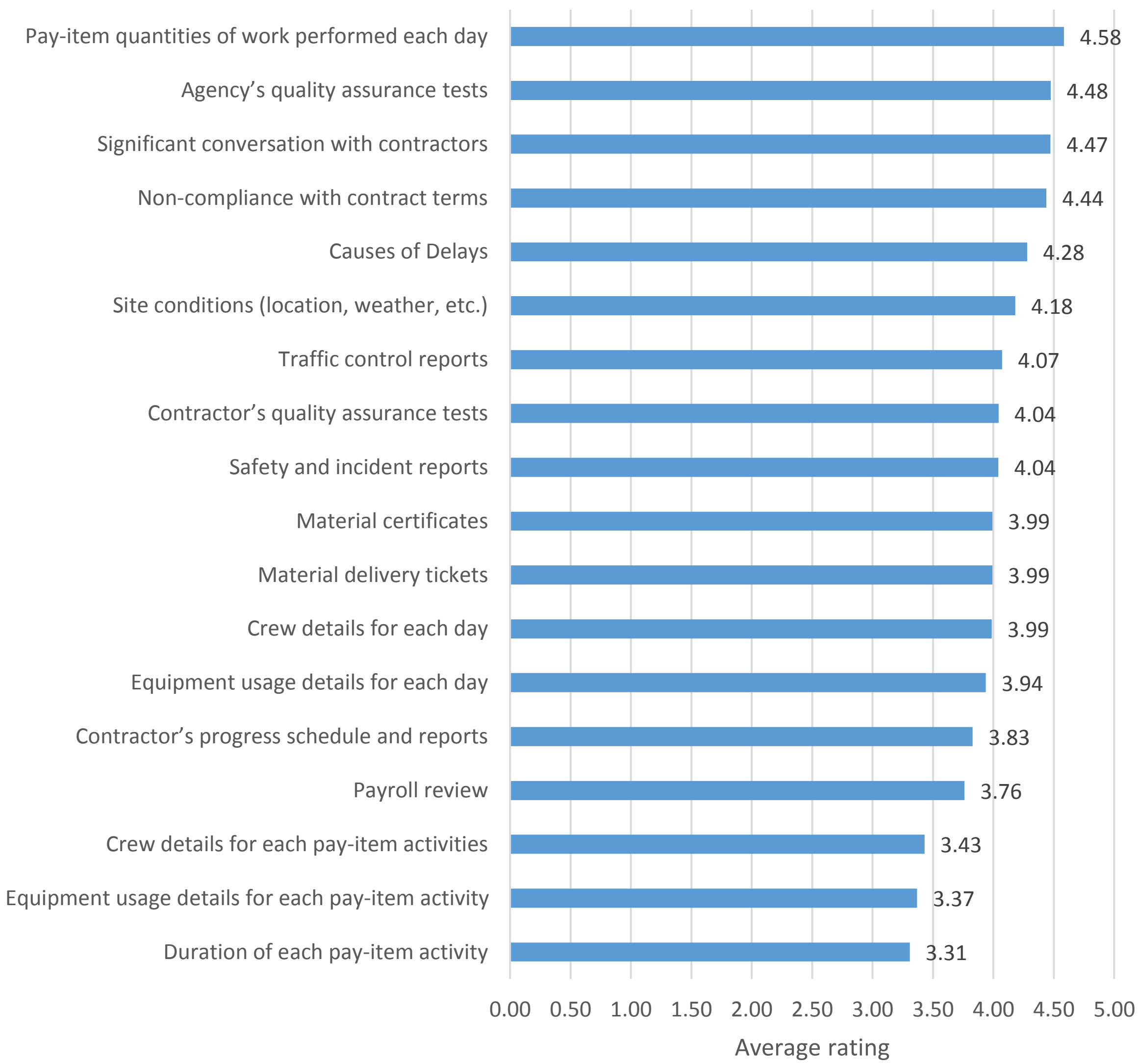


Figure 4.9 Average importance rating of DWR data for potential benefits.

Some of the data may be collected in multiple systems (e.g. Safety and incident reports). As such, the total sum of responses in Figure 4.8 for a given type of data attribute can be higher than the total number of respondents. For example, for safety and incident reports, the total number of responses were 167 (63+93+11), but the total number of respondents were only 155. Also, it may be noted that while some data are collected in the current DWR systems, they are not necessarily collected with structured attributes, but rather in linguistic comments. Such linguistic data (such as significant conversation with contractors, which is rated to be 4.47 out of 5 on an average) are more challenging to analyze because the linguistic data may require the use of text mining techniques to generate any useful insights or the data may need to be analyzed manually. Yet, those might be more important than many other data attributes collected in the DWR system.

Additional data considered to be important and collected mostly in the main DWR system include delay causes, significant conversations with the contractors, and non-compliance with contract terms. Other data attributes related to the quality assurance tests, safety data, traffic control, material certificates, material delivery tickets, contractors progress reports, and payroll reviews were not considered to be main items of the DWR data and are collected mostly in other forms and systems. But, those data were still considered to be very important, as most of those data were rated at more than 4 out of 5 (Figure 4.9). Many respondents stated that they do not collect the pay-item-activity wise crew, equipment, and duration data—possibly because of additional efforts required to collect the data and the underutilization of already collected DWR data. If the data that is already collected is not used properly, it may seem that the collection of even more data will not be useful.

Some other data identified from the survey that should be collected as a part of the DWR data are contract time charges, controlling activities, DBE requirement verifications, and erosion control reports. The use of the various data attributes to obtain benefits from the DWR data is presented with details in 5.

4.2.3 Applications and Benefits of DWR Data

Eleven applications and benefits that can be obtained from the DWR data were identified from the literature review and the interviews with Iowa DOT RCEs. The DWR data is perceived to be very important for obtaining various benefits, such as contractor payment, dispute resolution, and progress monitoring—all of which received the average ratings of more than 4 out of 5 (Figure 4.10). Time, budget, and quality are three aspects of progress monitoring (Wisconsin DOT 2014)—all of which are recorded in the DWR system. It can be concluded as before that the data collected in the DWR system is vital for the progress monitoring, which is further used for the contractor payment or pay application approval. In addition, those applications are automated in many current DWR applications so that RCEs do not have to go through those manually to calculate the overall progress or the amount of payment required for a given project. Even better, the overall progress of all the projects throughout the state can also be monitored by querying the recorded DWR data. Similarly, the use of DWR data for dispute resolution came as one of the top three applications for which DWR data is considered vital. Caltrans (2010) believes that DWR will reduce the payout rate of claims and disputes and the cost of research associated with those.

The DWR data are also considered important to generate as-built information, identify various project risks, such as cost overrun and schedule overrun. The majority of the respondents also reported that they were using DWR data for as-built information generation. However, only about half of the respondents were using DWR data for generating the activity cost estimation, production rate estimation, and contractor evaluation. The first two benefits can be obtained if the activity level data was collected. However, the results of the survey show that the respondents are not very interested in getting those benefits—possibly because the information would be beneficial to other departments (which manages the departmental resources for future projects) rather than the respondents (mostly RCEs). As such, it is hard to realize that such information would be beneficial. In addition, it should be noted that there are limited automation to no automation in the current electronic DWR systems for utilizing the DWR data for dispute resolution, as-built information, activity cost estimation, production rate estimation, contractor evaluation, and contract time determination.

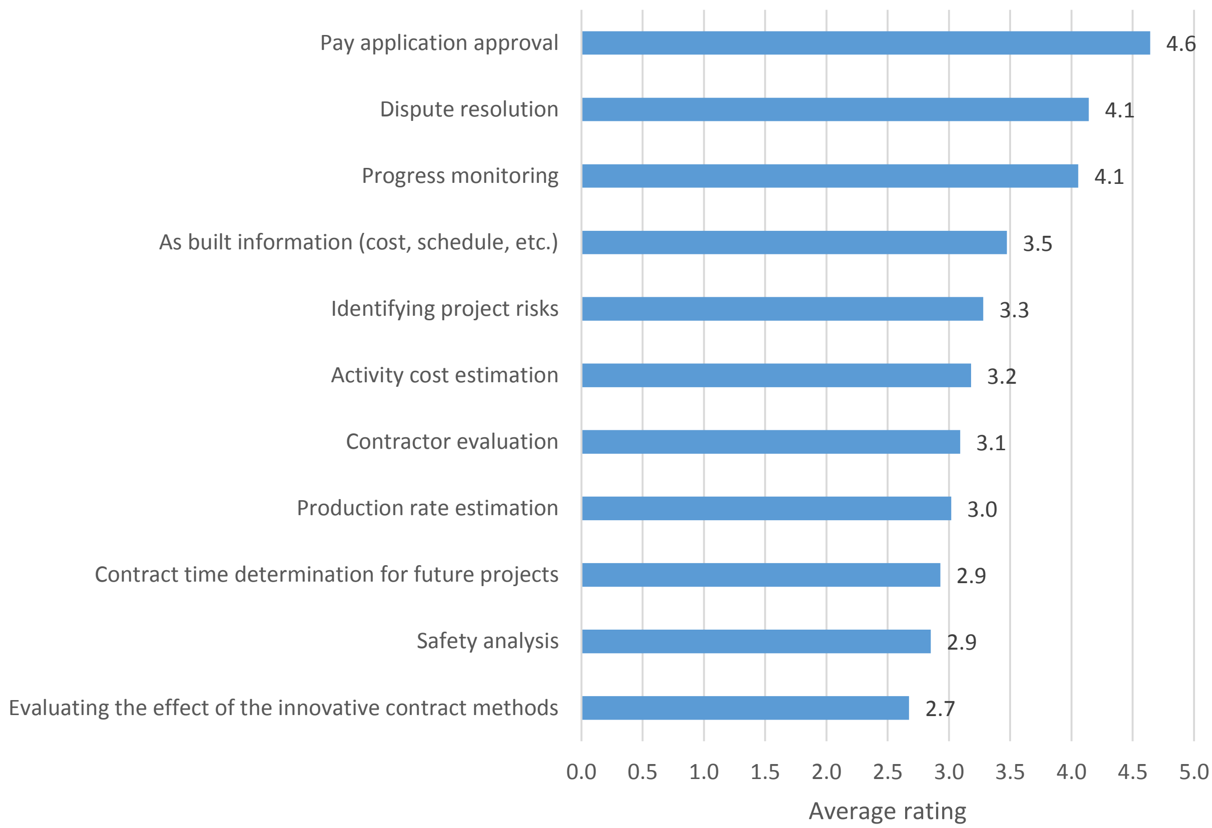


Figure 4.10 Average rating for the importance of DWR data to obtain the benefits

Most of the state DOTs did get the top three benefits for which DWR data were considered to be very important (rating of 4 or above) (Figure 4.11). Interestingly, the next four benefits for which DWR data were considered important (rating of 3 or above) were also obtained by more than half of the respondents. While the respondents did respond that they have estimated production rates based on the DWR data, most of the current DWR systems do not have a function to collect accurate production rates. This is mainly because the resources (equipment, crew, and material) for activities are not tracked properly. The current data collection systems are mostly limited to resources (equipment, crew, and material) tracking for every day.

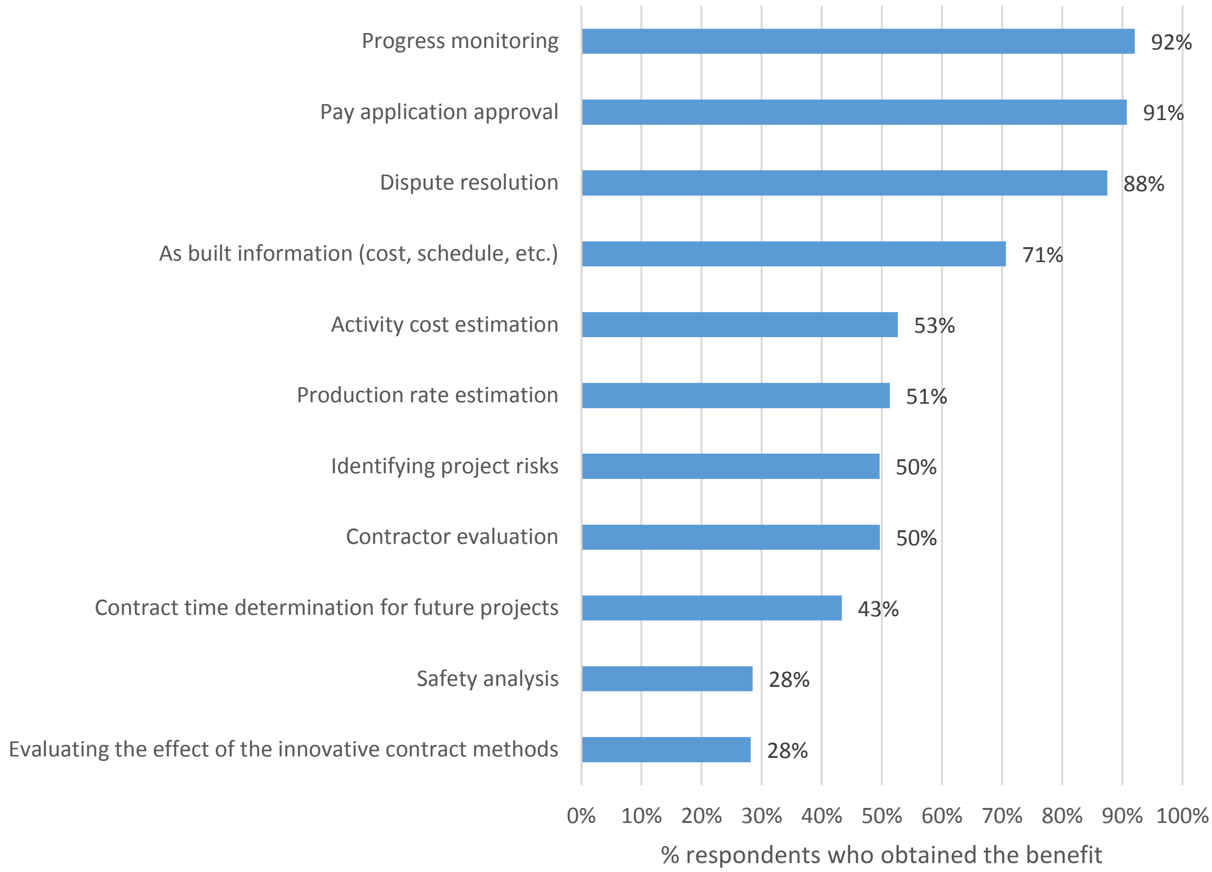


Figure 4.11 Percentages of respondents who obtained various benefits from DWR data.

Some additional applications and benefits of the DWR data as identified from the survey include legal issues, verification of labor compliance (e.g. Equal Employment Opportunity (EEO), prevailing wage rate verification), generate reports (such as amount of asphalts used in a given year), future resource allocation, and recording the change orders or project overruns. It can also be used for documentation of pertinent conversations and on-site meetings with contractors, and agencies' quality assurance inspections. Similarly, it can be used to identify the design issues and inadequate specifications, requests for data for the Freedom of Information Act (FOIA) and Sunshine Act, and paperwork reduction. The DWR data can also be used to keep track of weather on site, ongoing work activities, material costs, controlling work items, liquidated damages, various dates (such as submittals, closeouts, etc.), and contractors' equipment and crews. Those applications are used in 5 to develop an advanced framework for utilizing DWR data.

Figure 4.9, Figure 4.10, and Figure 4.11 combined gives an interesting insights regarding the importance and use of DWR data. Figure 4.9 shows that various DWR data attributes are considered to be very useful, i.e. nine out of 18 data attributes were rated at above 4 out of 5. Figure 4.10 shows that DWR data is useful for many applications, i.e. seven applications are rated at or above 3.0 out of 5. But, only four out of 11 application benefits were obtained by more than two thirds of the respondents according to Figure 4.11. Thus, there is a widespread realization of the importance of DWR data among DWR system users but limited benefits are being obtained by analyzing the data. However, the importance of DWR data may not be realized by other user groups of the same state DOTs.

4.2.4 Challenges with Existing DWR Systems

The state DOT representatives were asked to write down the challenges for utilizing the current DWR systems and DWR data that is being collected. The respondents provided linguistic answers regarding issues and challenges specific to their DWR systems as well as generic challenges related to the DWR systems and practices of DWR data collection. In this section, first, the challenges associated with the DWR systems and practices are presented and are then classified into six categories. Those challenges identified are then used to develop an ideal framework for an advanced DWR system in 5.

Challenges Specific to DWR Systems

The strengths and areas of improvement for various DWR systems currently being used were identified. Table 4.1 below presents the strengths and areas of improvement to tackle the challenges in the current DWR systems used by various state DOTs based on the survey and extensive literature review (Oklahoma DOT 2010; Vermont Agency of Transportation 2011; AASHTO 2014a; Homberg and Gallegos 2007; Kansas DOT 2013; PennDOT 2007; SDDOT 2008; UDOT 2006; DelDOT 2007; MnDOT 2008; Illinois DOT 2014). Many state DOTs were using the ASM. As such, more comments were received regarding the issues and areas of improvement of the ASM.

Table 4.1 Strengths and challenges of the current electronic DWR systems

System	State	Strengths	Areas for improvement
AASHTOWare SiteManager (ASM) – Daily Work Report	Multiple states	• Comprehensive data attributes • Templates for customizations • Shared source code for customization e.g. additional remark types • Funding from multiple state DOTs • Document attachment	• User interface improvements • Add a search functionality for the diary • Add a functionality to track time spent on particular activity • Add functionality to record detailed data such as two equipment with two foreman for same activity • Simplifying the data recording process such as change order • Auditing problem in material test results • Expectations for the future work locations and time required for its completion • Work progress data input directly from contractors • Improve contractor performance analysis functionality
Vermont Managing Assets for Transportation System (MATS)	Vermont, New Hampshire, and Maine	• Comprehensive data attributes • Strong link to asset management and payment systems • Type and search functionality in the tables/lists • Funding from multiple agencies	• Integration with the bidding, materials & research, and labor compliance • Rapid development without wider vision
AASHTOWare FieldManager (FM) – Inspector's Daily Report	Michigan and Iowa	• Comprehensive data attributes • Attention flag to quickly locate the items with potential issues • Funding from multiple agencies • Document attachment	• Integration with the asset management
Arizona PEN	Arizona	• Use of existing credentials for user authentication • Formatting option for the linguistic data • Diary search function • Built in quantity calculator • Document attachment	• Location data attribute cannot be recorded
Construction Management System (CMS)	Kansas	• Use of existing credentials for user authentication • Minimalistic data recording effort	• Update the system • Addition of structured data fields for equipment, labor, weather, etc.
PennDOT Construction Documentation System (CDS) NeXtGen –	Pennsylvania	• Comprehensive data attributes	-

System	State	Strengths	Areas for improvement
Project Site Activity			
Construction Measurement & Payment System (CM&P) – Item Installation	South Dakota	• Minimalistic data recording effort	• More structured data field
Project Development Business System (PDBS) – Field Book	Utah	• Vision of tightly integrated system for the DOT systems • Comprehensive data attributes	• Improved user interface
Field Data Collection (FDC) – Field Data Collection	Delaware	• Time-wise temperature recording	• Regular update • Universal prepopulated lists rather than the arbitrary addition of items in the list • Use of existing user accounts
Field Operations (FieldOps)	Minnesota	• Built in quantity calculator	-
Illinois Construction Records System (ICORS)	Illinois	• Ease of implementing the state specific requirements	-

In addition to the points mentioned in the, several other points were noted from the survey mostly related to the ASM. Tennessee DOT, for example, noted the duplication of basic job information entry in the ASM. Similarly, Colorado DOT noted that they do not track the material information and certifications, as those are not available in the ASM they currently use. Oklahoma DOT wanted to collect more in-depth DWR data for larger projects with multiple contractors that ran over contract time. The need for web-based DWR system is also understood by AASHTO and, hence, they are developing their web-based DWR system.

Overall, ASM, MATS, FM, PennDOT CDS NeXtGen, and Utah PDBS have a fairly comprehensive data attributes for collecting DWR data. Other DWR systems like Kansas CMS, South Dakota CM&P, Delaware FDC, Arizona Pen, and Minnesota FieldOps have minimalistic data attributes for collecting DWR data. While those systems are not developed to collect the resources data in the system to the activity level (labor and equipment hours for each activity) unless force account is used, the paper-based DWR system used by Caltrans has an activity-level resource data collection system and they have been collecting the resource level data as per one of the Caltrans respondents. Additionally, the response of the survey indicated that while data collection itself is challenging, utilizing that data has been even more challenging because of the lack of understanding of collected data among the DOT personnel and complications resulting from the use of multiple systems.

Generic Challenges Related to DWR Systems

The generic challenges and issues identified from the survey are presented in six different categories below.

Quality of data. Many state DOTs expressed their concern over the accuracy, consistency, timeliness and completeness of the data collected by the field personnel (Arizona, Arkansas, Connecticut, Florida, Kentucky, Missouri, Montana, Nebraska, New Jersey, New Mexico, Ohio, Oregon, South Dakota, Texas, Virginia, Washington). Some inspectors and RCEs do a great job of providing sufficient details while others leave out some of the details. In addition, the state DOTs may not collect the quantity data in the same day as the work being completed. That means analysis of progress (or time) in relation with the quantities may not be possible. Also a simple and easier user interface can result in better consistency and completeness of data entered (Nebraska).

Resource limitations. Having sufficient time and personnel to record all the required data is challenging (Colorado, Minnesota, New Mexico, Tennessee, and Texas). Field personnel may not be comfortable with using computers. In addition, not enough people who are knowledgeable of technologies are entering the construction industry, resulting in challenging environments to implement technological innovations (Idaho, Oklahoma, and Texas). At the same time, there is a high turnover of the field personnel (Montana, Virginia). Adequate training is required for such uniformity and accuracy while collecting DWR data (Delaware, New Mexico).

Duplication of efforts. Although electronic DWR is supposed to help the state DOTs to reduce the duplication of efforts to record, process, and utilize DWR data, state DOTs noted that there is still a duplication of efforts in different systems due to various policies or lack of integrations (Delaware, Georgia, and New Mexico, Washington). An integrated solution that is used department-wide for the various aspects of construction (bidding through complete construction) would be an option to reduce duplication of efforts (Delaware, Oregon, and Pennsylvania). In addition, some state DOTs first record DWR data in paper form in site and then transfer it to the main application later (e.g. Ohio). This could be changed if a proper laptop or a tablet with a keyboard and a better screen (that are visible under bright conditions), along with corresponding DWR system with simplified interface, were provided to the construction personnel (Colorado, Idaho, Missouri, and Ohio). Some states have been transitioning to eliminate this duplication of effort by purchasing proper tablets and/or notebooks (e.g. Ohio). But the policies that require paper-based documentation and signature for various reasons (such as giving more weightages on original paper document in litigation, requirement of "wet signatures," federal requirements) is hindering the advancement towards complete electronic documentation.

Lack of Proper Data Attributes. A respondent from Arizona noted the challenge of translating the historical data into the useful information for future plans when dealing with situations like incident analysis. Proper data attributes, rather than linguistic data, would be more useful for generating useful information. Analyzing data using text analytics would be harder because of spelling, grammar, and standard abbreviations, etc. However, it may be possible to identify a set of useful data attributes using simpler text mining techniques by finding the frequently collected comments.

Technical limitations. There are a number of technical limitations identified from the survey. Virginia DOT noted that currently, only contract specific data are being analyzed. Analyzing multiple databases will complicate the process and there is the issue of interoperability. Similarly, South Dakota mentioned the lack of statewide Internet connectivity as an issue to using a web-based DWR system. Some states noted the need for better hardware (bigger servers to handle more contracts and faster computers for running the software quickly) (New Mexico, Texas), while others have noted a lack of enough hardware (FDOT 2000).

Current Business Practices. While a lot of DWR data are collected by the state DOTs, only current DWR system users are aware of the level of data being collected and its importance. Outside of the current DWR system users, other user groups within the state DOTs are not well aware of the level of data being collected. As such, the state DOTs would not spend time identifying the questions that can be answered from the DWR data analysis. Similarly, there are issues with the current practices of collecting the data. This limits the use of those DWR data.

In addition, the use of an electronic system in some districts and use of paper-based systems in other districts creates even more fragmentations and issues to analyze the statewide data. In Alaska, for example, ASM is being implemented in only one region—other regions still uses paper-based DWR systems which are hard to retrieve quickly for analysis. Oregon DOT also noted the same issue.

4.2.5 Analysis of Partnering Between State DOTs to Develop a Common DWR System

One of the notable aspects of DWR systems is the use of a partnering approach to reduce the cost to develop a DWR system. MATS, for example, was developed by a tristate partnership and have enabled savings of millions of dollars for the three states (Fowler 2010). Similarly, AFM was initially developed by Michigan DOT which was then further developed under AASHTO to reduce the development costs by sharing the cost from multiple state DOTs. AFM is most notable in terms of cost saving. It is being used by 21 state DOTs and Michigan DOT noted a cost saving of $22 million by using the system (Couto 2005). Potential cost saving might be one of the major reasons that Connecticut DOT—which developed one of the earliest DWR related systems (Construction Management and Reporting)—is now using ASM. However, another aspect of utilizing such common system is the concern regarding “one size does not fit all.” Each state DOT has their data recording and reporting requirements. Any changes in the DWR system needs to be approved by AASHTO, and it may take more time before the changes are approved and implemented compared to making and implementing changes in State Specific Systems (SSSs). To tackle this issue to some extent, AASHTO provides a portion of the codes to the state

DOTs to customize ASM. Additionally, the state DOTs can add additional reporting capabilities in the system. As a result, state DOTs such as Arkansas Highway and Transportation Department (AHTD) have customized the system and also developed custom reporting systems called Arkansas SiteManager Access Reporting (SARS). Virginia DOT has also developed a dashboard to see weather impact, item overrun/underrun impacts by location or projects, accident analysis, value engineering, internal audit investigations, etc. Missouri DOT modifies the shared portion of the code to customize the system to meet their policies and requirements. Yet, some states have moved forward to developing their own DWR systems. For example, Alabama DOT, which is currently using ASM, is in the process of developing their own web-based DWR system along with companion mobile application. Caltrans also tried ASM but decided to develop their own integrated system.

4.2.6 Findings from First Nationwide Questionnaire Survey

The study found that only three state DOTs are now relying on a paper-based DWR systems for collecting, storing, and analyzing DWR data. Such paper-based DWR data are not easy to analyze for getting any of the benefits identified in this study. A majority of state DOTs are transitioning to the electronic DWR systems and using a paper-based system alongside to supplement the electronic DWR systems. Other state DOTs have already transitioned to the utilizing the electronic DWR system only. The study found three electronic DWR systems developed, maintained, and implemented by the combined effort of multiple DOTs. It also found six State Specific Systems (SSSs) developed, maintained, and implemented by single state DOTs. Out of all the systems, AASHTOWare SiteManager (ASM) is the most popular application in terms of the number of states using it as well as the number of survey respondents using the software as per the survey results. The combined effort of state DOTs to develop and maintain a common system have a huge benefit of cost saving. At the same time, state specific requirements for data collection, reporting, and need for all participating DOTs' agreement to make any new proposed changes to the system before its implementation are some of the challenges associated with such a common system. To tackle the state specific requirements, AASHTO shares a portion of the source code so that the state DOTs can customize the software to some extent. Additionally, a reporting system is also provided to generate customized reports that meet the state's requirements.

While the traditional move has been the movement from paper-based DWR systems to desktop based DWR systems, there is another trend toward the evolution of the DWR systems—the web-based and mobile device-based DWR systems. The web-based DWR systems have benefit of reduced system maintenance costs and real-time data updates. The mobile device has the benefit of eliminating the duplication of efforts, easing the DWR data collection, and, again, real-time data updates. As state DOTs better understand web-based and mobile device-based systems, many state DOTs have started migrating toward those new DWR platforms.

The study identified 11 applications and benefits of DWR data, out of which DWR data was ranked to be very important (rating of over 4) for three of those applications. Those three applications are pay application approval, dispute resolution, and progress monitoring. Those are the very fundamental reasons for which DWR systems were developed. The DWR data was also ranked to be important for five other applications (rating of over 3)—as-built information, identifying project risks, activity cost estimation, contractor evaluation, and production rate estimation. It was also noted that while DWR data was considered to be very important for many application benefits, fewer respondents have obtained those application benefits.

A number of other challenges were noted in the study regarding a better utilization of DWR systems to collect, store, and analyze DWR data. Those challenges were classified into six categories:

- Quality of data
- Resource limitations
- Duplication of efforts
- Lack of proper data attributes
- Technical limitations
- Current business practices

The data quality issue was the most noted challenge for the active utilization of the DWR data. One of the reasons behind poor DWR data quality is the limited resources available to record the data in site. Not enough staff members are available and they may not have enough training to collect complete, consistent, timely, and accurate data. Without such data, it may be challenging to generate meaningful results by analyzing such data. Additionally, not enough data analysts are available for analyzing the DWR data in relation with other available databases and different decisions through the project delivery process that may benefit from DWR data. At the same time, even after using electronic DWR systems, there is still a duplication of efforts resulting from various state and departmental policies like "wet ink" requirements. Such requirements essentially necessitate the collection and storage of data in paper-based as well as electronic systems. Additionally, technical issues such as lack of proper devices that can be used in field also necessitate the DWR data collection in field followed by their transfer to an electronic system when they reach office. Similarly, lack of an intuitive interface/process was noted by some respondents in their DWR systems, which can essentially create a data quality issue. Also, lack of proper Internet connectivity, staff turnover, and limited capability of text analytics to analyze linguistic data are additional technical challenges toward better collection, storage, and utilization of DWR data.

As noted before, there is a lack of complete data collection for the data attributes that can already be collected in the system. Additionally, there is a lack of data attribute collection fields in those systems. While all electronic systems did not have the functionality to collect activity level resources data, some of the systems had even less data attribute collection fields. Those systems relied on linguistic data for most of the data except quantity data. Finally, although the current DWR system users have a good understanding of the DWR data being collected and its importance, there is a lack of understanding of the current data across the DOT personnel. This is another issue that is preventing better utilization of the DWR data that is already collected. Those findings are aligned with the statements hypothesis made in Woldesenbet et al. (2014), which presented three possible reasons for poor usage of highway project data:

- Minimal recognition or interest in using these data in the context of supporting various decision-making processes during the lifecycle of a highway project,
- Lack of in-house resources and capabilities to analyze the data, and
- Poorly defined procedures and mechanisms used to extract, process, and analyze the data to generate useable information and knowledge to assist highway project decision makers.

Finally, the current utilization of the DWR data has been limited to the reporting of historical DWR data and no efforts have been made toward the use of predictive analytics. As such, various trend analyses, such as quantity overrun/underrun by items, project types, locations, etc., can be done to identify various associations hidden inside the data. Such relationships are not necessarily causal, but those patterns can be used for predicting various aspects, such as quantity deviations, for future projects.

4.3 Contractors Interviews

Two site supervisors working in construction companies were interviewed to understand the contractors' practices of collecting DWR data. The interview guideline is provided in Appendix D. One of the two companies was relying on production rates from the experience and virtually tracking no information on site except some notes on papers. The company tracked the progress and any issues via weekly meetings with owners and subcontractors.

Another company utilized HCSS Heavy Job software to collect and analyze DWR data, which can be used for multiple applications such as production rate estimation, maintenance of equipment, tracking of job progress, and recording of significant events. The company also noted the challenge of collecting a reliable field data as the biggest challenge.

While the interviews were limited to two companies, it does indicate that small to medium companies may not spend much time and resources keeping track of their labor, equipment, and progress details on a daily basis. But, larger companies utilize DWR systems developed for contractors to keep track of historical production rate information among others.

4.4 Second National Questionnaire Survey Results

The second questionnaire was conducted to understand the current level of automation of various applications that were identified from the literature review, the first nationwide survey, and interviews. The questionnaire is provided in Appendix C. The level of automation is used as an indicator of the presence or availability of an effective algorithm for its applications and decision making based on that. Respondents were also given an additional field to comment about the automation rating they provided. Additionally, the questionnaire also explored the possible and current users of the DWR data within the DOTs, and also current and possible benefits obtained by various user groups within the DOTs. The possible and current levels of benefits are collected to identify the gap between the possible applications of the data with the current applications of the data. They were given additional comment fields to provide details about the use case for each user group. Finally, the respondents' opinions about the addition of several new features in their DWR systems were solicited to understand the possible usefulness of those features.

The survey was conducted from August 13 to September 2, 2014. The questionnaire was sent to 115 state DOT engineers and responses were received from 44 respondents (response rate of 38%). The respondents represent 27 state DOTs.

The first part of the results presents the existence and possibility of systematic algorithms for various applications, while the second part presents an additional gap between current and possible applications and utilizations of the DWR data.

4.4.1 Existence of Systematic Algorithms and Methodologies (or Lack Thereof)

Respondents were asked to rate the current level of automation to obtain various benefits from the DWR data. Those ratings are then combined and presented with the ratings of the importance of the DWR data for obtaining those benefits and the percentages of respondents who have obtained the benefits (Figure 4.12). The later parts (importance of the DWR data to obtain those benefits and the percentages of the respondents who have obtained the benefits) were obtained from the first nationwide survey. Overall, there is a consistency between the level of automation for an application, the current condition of the benefits, and the usefulness of DWR data for those applications. Thus, many application benefits were possibly not obtained because of the lack of the automation for obtaining those applications. The results of the survey and its analysis are presented in detail below for each application.

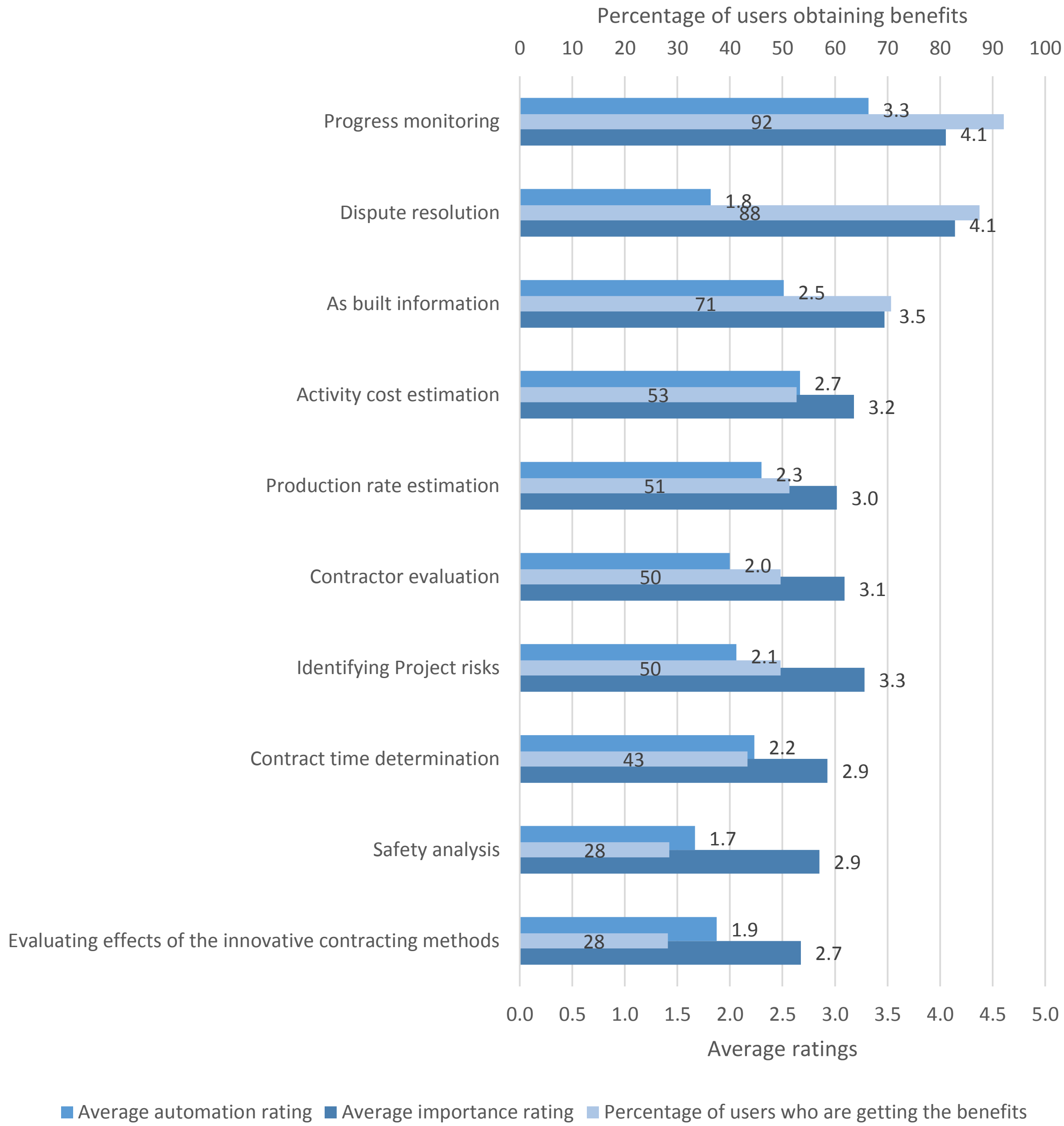


Figure 4.12 DWR data importance for various applications, current benefits obtained, and level of automation (ratings are from scale of 1 to 5, 5 being most important or most automated)

Progress Monitoring

Progress monitoring is the most popular application of DWR data and is automated to the highest level compared to other applications. It is also rated as the most important application of the DWR data. The DWR system is used daily (or frequently) to collect the data, like quantity of work done for each pay-item, materials used, and labor and equipment hours, which are then used by the system to automatically generate the current level of progress in terms of total quantities. It is then used by the system to generate the payments to be made to the contractors on a regular basis (e.g. biweekly, monthly, etc.). Automating this procedure is fairly straightforward and hence has been automated properly in DWR systems. Additionally, the progress can also be tracked using the number of working days used and the number of working days remaining.

Although the progress monitoring has mostly been automated, the process of recording the DWR data that is used to generate the progress information is still manual. Newer data collection systems such as barcode, Radio Frequency Identification (RFID), and Light Detection and Ranging (LiDAR) can be used to automate the data collection. This is discussed in more detail in 5. Moreover, visualization techniques can also be used to visually monitor the work progress which is more useful from the perspective of upper management and the public. For that, the project Linear Referencing System (LRS) data or the coordinates of the activities that are already recorded in the system can be used and linked with a mapping system. This can become a part of a travelers' information website. Additionally, the progress against time can be visualized to see the construction rate. This can be used, for example, to identify the improved production rate or possible issues that delayed the progress.

Activity Cost Estimation

DWR data can be used to estimate costs of activities for current projects based on the quantities of work done so far. This process is fairly simple and can be automated. As such, respondents rated the activity cost estimation to be automated to a good degree (2.7 out of 5). DWR data with proper data attributes can be further used to calculate activity costs based on resource utilization, i.e. material costs, equipment, and labor costs used for the activity. This is the cost estimation methodology used by contractors. However, currently not enough data is collected for pay items except in case of the force account items. In force account items, detailed data such as equipment and labor hours are collected for each item, which can be used for estimating activity costs. State DOTs use the data collected for force account to estimate appropriate payments to the contractors for added items. Such data can be further used to estimate the costs of activities based on resource utilization for future projects.

As-built information

The DWR data can be used to generate as-built schedules, as-built quantities, and as-built costs. The level of automation of developing such as-built information is average (2.5 out of 5). The as-builts give a big picture of cost, quantity, and schedule deviations of projects compared to planned cost, quantity, and schedule. When such deviations are larger, formal change orders are required. Iowa DOT, for example, needs to process a change order when the deviation, such as quantity overrun, underruns, or the addition of new contract items, amounts to $10,000 or more (IaDOT 2005). However, if such deviations are smaller, those data are recorded only in the DWR system and the connected/accounting payment system. In both cases, the data regarding changes will be collected and stored in DWR systems. These data can then be used by the system to automatically generate as-built schedules, as-built quantities, and as-built costs. As built-costs and as-built quantities are fairly straightforward to generate, but generating as-built schedules will have some complexity. Current level of details collected by the DWR systems can be used to generate simpler as-built schedules, but to develop more informative as-builts containing the critical path and links between activities, more data may be required. One state DOT representative stated how important the as-built information is and then noted that historical as-built that can be used to improve future project planning has not been used for that purpose as of now. When as-built schedules with proper links between the project activities are developed, they can be used for delay impact analysis. Such analysis can become a valuable tool to resolve disputes related to delays.

Production rate estimation of pay items

The current level of data collected in the system does limit the potential of generating production rates to some extent (Rich 2006). Yet, studies have been conducted to generate reasonable approximation of the production rates from the DWR data (A. Woldesenbet, Jeong, and Oberlender 2012). The survey results indicated that production rate estimation has been somewhat automated (2.3 out of 5). It can be assumed that some of the state DOTs have used the force account data to generate production rates that they would use later for claims regarding additional work items. Some DOTs might keep track of actual production rates only when there is any issue or extra works. But, keeping track of actual production rates in the field is important not only to deal with the claims regarding change order costs but also to estimate realistic contract time determination. However, it was found that at least one of the state DOTs have relied on the data from RS Means calculation for the production rates rather than the actual production rates from the field.

Contract Time Determination

Contract time can be determined for future projects based on the production rates calculated from DWR data for previous projects. Thus it needs additional steps other than generating the production rates. As such, the level of automation among the state DOTs also was slightly lower for contract time determination (2.2 out of 5) compared to the level of automation of production rate generation (2.3 out of 5). The lower rating of automation of contract time indicates that there is a lack of proper methodology to determine the production rates based on the DWR data. The determination of contract time involves the production rate calculation as well as the understanding of interlinks of the items (construction sequence, critical path). Construction sequences can be also be learned from the historical data using data mining techniques. But for better understanding of the links between the items and critical paths, additional data might be required from the field.

Identifying Project Risks

The pattern of cost and schedule overruns can be identified from historical projects. For example, particular items might generally be associated with quantity deviation or a particular type of project might be associated with higher percentage of cost overruns, etc. Those patterns can then be used to quantify the probability of project risks for future projects depending on its size, type, locations, and pay items. This can be achieved by using frequent pattern analysis and association rule mining. As such, the current level of automation for this application was found to be medium (2.1).

Contractor Evaluation

Contractors are currently evaluated by filling out a contractor evaluation form after the project is complete. In terms of recording this evaluation information and using it for future, the process is somewhat automated. However, in terms of automation of contractor evaluation—factors such as the percentage of activities delayed or completed on time, quantity overrun or underrun, time required to fix any issues notified by the inspectors and RCEs—are still not automated. Some of those factors can already be generated based on the current level of DWR data while others may require some additional data collection.

Evaluating Effects of Innovative Contracting Methods

The effects of innovative contracting methods can be analyzed based on factors such as quality of final products, material inspection results, cost deviation, quantity deviation, and schedule deviation. Those analyses require complex data mining techniques and have not been automated as a part of current DWR systems. However, the system does collect enough data to make such analyses. There is also lack of recognition or interest in getting this benefit.

Dispute Resolution

Disputes are prevalent in the construction industry. There are many possible reasons for disputes, including a delay, compensation for delays, day charging, differing site conditions, etc. The delays can, for example, be caused by the contractor, DOT, both parties, or neither parties. There is a need to identify and categorize the disputes into two categories—one that can be analyzed automatically using DWR data and another that needs manual work. For example, disputes regarding compensation rates for additional works can be analyzed using the DWR data but request for time extensions because of differing site conditions cannot be automated. Due to the possibility of having many different types of disputes, automating all dispute resolution is very hard (and is indicated by an automation rating of 1.8 out of 5). However, some of the dispute resolution processes might be automated.

Safety Analysis

Similar to dispute resolution, safety analysis also encompasses a broad meaning. When there are any incidents in the construction site, its causes can possibly be analyzed using the DWR data. Current practices were limited to the collection of remarks data, which is not very useful for automating such analysis. This mostly limits the automatic analysis to the determination of incident patterns in relation with other parameters, such as project type and location. The type of traffic control used, the number of injuries and fatalities, etc. can be some of the attributes that can be collected in the DWR data which will be useful for automating safety analysis.

4.4.2 Additional Results

The current utilization of the DWR data by other departments was also assessed. The results of the study show that DOTs have been consistently lagging behind in terms of utilization of DWR data by various teams within the DOT (Figure 4.13). For example, while 36 respondents stated that a cost estimation team can possibly benefit from the DWR data, less than half (13) of them stated that their cost estimation teams are utilizing the data. This is a huge gap that possibly resulted from the lack of understanding of the level of data collected in the DWR data and/or lack of proper methodologies to be used by those teams. A similar gap can be seen in all but one team (auditing team). As one of the state DOT representatives stated, the teams within the DOT may not have a good idea of the detailed data being collected by inspectors and RCEs.

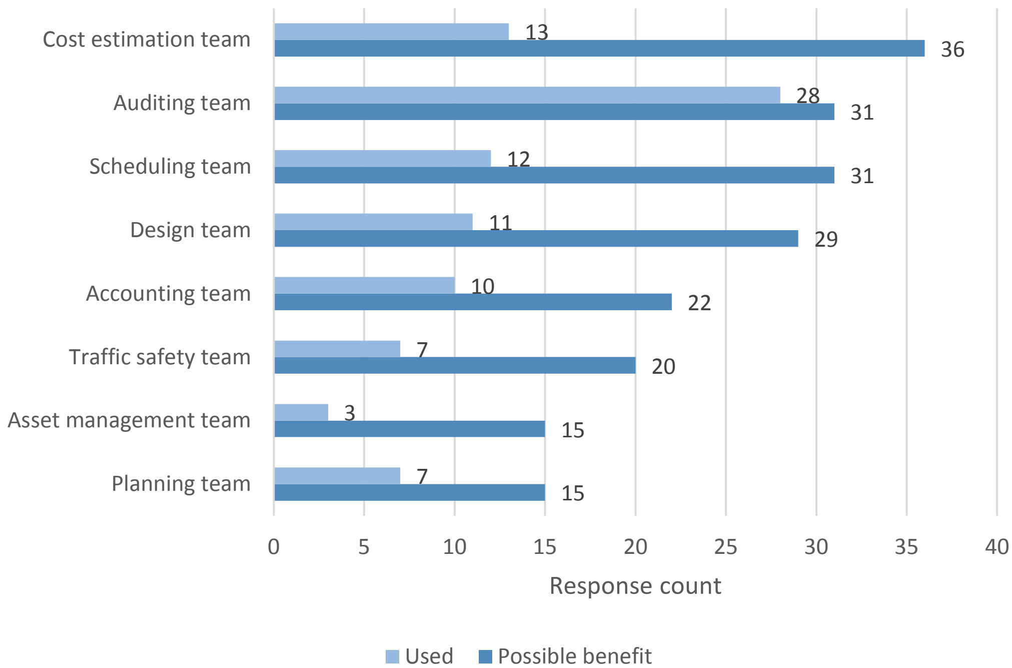


Figure 4.13 Possibly benefiting and currently benefited teams

Another question seeks respondents' opinions toward additional features that can be integrated in current DWR systems. The DOT representatives showed interest in integrated weather data collection, i.e. collection of web-based weather data from other sources or even from the (Internet) connected weather data collection equipment. This can save inspectors' and RCEs' time entering the weather data and can focus on entering other important data. The other three additional features regarding the use of predicting activity completion time, use of RFID, and use of barcode received an average rating. The predictive activity completion time can notify inspectors about expected completion of a particular activity, which he can use to check possible delays in the activity completion date. RFIDs and barcodes can aid in easing the data collection effort as with the web-based weather data collection system.

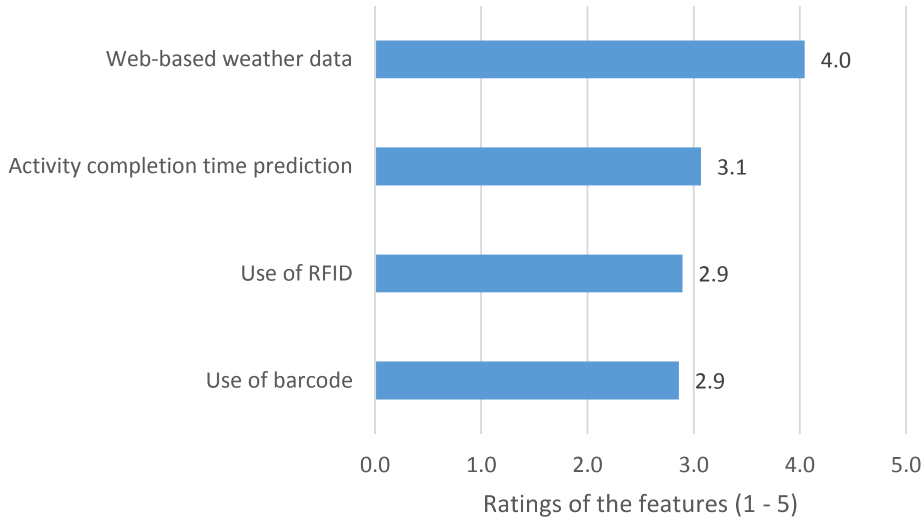


Figure 4.14 Ratings of the additional features for DWR systems

Finally, estimated extra efforts required to collect activity level resource data (as opposed to day level resource data) were requested. As opposed to the researchers' estimates, the result showed that such a level of data collection may increase the extra effort by as much as half the current effort when such data is collected for all the pay items. If such detailed data is collected for major pay-items, the extra effort can be as low as 10% (in terms of mode).

Table 4.2 Extra effort required to collect pay-item level resources details for all and major pay-items

Statistics	All pay-item level	Major pay-item level
Mean	62%	42%
Median	50%	25%
Mode	50%	10%

4.4.3 Findings from Second Nationwide Survey Questionnaire

The second questionnaire survey focused on identifying the automation potential for various applications. Based on the results of the survey, a summarized table is presented below regarding possible lag of automating those tasks (Table 4.3). For the automation level categorization, ratings of 0 to 2 was considered as low automation, ratings of 2 to 4 was considered as medium automation, and ratings of 4 to 5 was considered as high automation.

The study also found that there is a consistent lag in terms of utilizing the potential benefits of the DWR data by various other user groups or teams within DOTs. For example, while 36 respondents stated that DWR data might be used by the cost estimation team, only 13 believed that they have been using the DWR data.

The respondents also showed interest toward the addition of integrated devices and technologies such as a web-based weather data collection system to automate the DWR data collection. Use of RFID and barcode were also of some interest to the respondents. Similarly, generating predictive activity completion duration was also interesting to the respondents. Finally, while the collection of additional data (activity level data) has the potential for automating various analyses to the next level, such data collection for all items would require additional effort, which is almost half the current effort and hence is not recommended in the current scenario of reduced workforce. However, the collection of such detailed data of major pay items may require as little as 10% additional effort and can be recommended as such efforts are likely to pay back in terms of automating various analyses.

Table 4.3 Lag in the possible and current level of automation of various DWR applications

Item	Possible automation	Current automation level	Automated to the extent possible	Remarks
Progress monitoring	High	Medium	No	Automatic weather data, RFID, barcode can be implemented.
Dispute resolution	Low to high	Low	No	Extra work compensation rates, etc. can be automated.
As-built information	Medium to high	Medium	No	Generating activity links in as-built schedule is challenging and requires data mining techniques. As built-costs and as-built quantities are fairly straightforward.
Activity cost estimation	High	Medium	No	Additional data can be collected to calculate activity costs from resources utilization perspective.
Production rate estimation	High	Medium	No	Activity level data should be collected.
Contractor evaluation	Medium	Medium	No	Results were more indicative of the contractor evaluation data entry and utilization in future. There is no automation in terms of utilizing other DWR data to evaluate contractors.
Identifying project risks	Medium	Medium	No	Historical risks are identified but not necessarily used for future projects. Data mining techniques like frequent pattern analysis can be used.
Contract time determination	Medium	Medium	No	Mostly dependent on production rates. Automating construction sequencing to automate contract time determination needs use of data mining techniques.
Safety analysis	Medium	Low	No	Additional safety data attributes can be collected to ease automation.
Evaluating effects of the innovative contracting methods	Medium	Low	No	Potential lack of recognition or interest. Benefit not obtained by many.

5 PROPOSED IDEAL FRAMEWORK FOR ADVANCED DWR SYSTEM

This chapter presents the detailed conceptual framework for the advanced DWR system. The proposed framework is based on the findings from the extensive review of existing DWR systems, the literature review, nationwide questionnaire surveys, and interviews with Iowa DOT residential Construction Engineers (RCEs). The overview of the complete framework is presented in Figure 5.1. The framework consists of seven major components:

- Data attributes and its relations (Data Model),
- Integration with the existing systems (Interoperability),
- Visualization of data,
- Advanced data collection systems,
- Automation of DWR analysis and reporting,
- Human factors, and
- Other technical aspects.

The first five components are more specific to DWR systems and are categorized under the DWR specific aspects. The systems used by state DOTs have a good set of data attributes that are collected by their systems. The systems reviewed also perform some basic DWR analyses fairly well, but other aspects of the framework were not implemented properly. For example, while AASHTOWare systems are integrated well together, AASHTOWare systems are not well properly integrated with other systems. None of the systems reviewed offer any functions for data visualization. Advanced data collection systems were barely utilized. The systems and their implementation also had some areas of improvement in terms of technical aspects and human factors. A quick summary of the current challenges and possible solutions that are used as one of the bases to develop the ideal framework are presented in Table 5.1.

Overall, an advanced DWR system can be used to:

- Improve the decision making process for future projects,
- Improve the project cost and schedule control,
- Reduce road users’ costs, and
- Improve the relationship between project stakeholders.

The details of each aspect of the framework are presented in the following sections.

Table 5.1 Challenges of getting benefits from DWR data

Challenge	Description of the challenges	Possible solutions
Quality of data	-Varying levels and quality of data provided by field personnel. -Staff turnover has added more challenge. -Inconsistency in the frequency of data collection	-Training, intuitive user interface to ease detailed data collection. -Update business practices if resources are available.
Lack of proper data attributes	-Some DWR systems have fairly comprehensive data attributes while others do not. -Many data are collected in linguistic format, which cannot be analyzed easily.	-Identify more data attributes using text analytics of the linguistic data. -Develop a DWR system with capability to collect those data attributes.
Resource limitations	-DOT resources have shrunken in past. -Not enough people who are knowledgeable about technologies are entering the construction industry, resulting in a challenging environment to implement technological innovations. -Not all field personnel may be comfortable with using computers.	-Introduce more efficient data collection methodologies. -Develop intuitive user interface. -Automation of various analyses and benefits.
Duplication of efforts	-State DOTs have policies such as "wet ink/signature requirements," which makes it necessary to use paper-based systems in addition to electronic systems. -Lack of integration has resulted in collection of various data in disintegrated systems. As a result, analyzing those data requires extra effort.	-Develop integrated systems and automated data collection devices such as RFID, bar code, LiDAR, and GPS. -Update policies to enable use of newer technologies.
Technical limitations	-Complexity when analyzing data from multiple disintegrated databases. -Lack of powerful and portable devices for data collection in field.	-Get newer devices and portable devices like tablets, lightweight laptops to ease data collection in electronic format directly in the field. -Develop web-based systems to ease the system maintenance.
Current business practices	-Lack of understanding of detailed data being collected in field.	-Communicating the detailed data being collected. -Brainstorming of the possible applications for other teams within an agency.

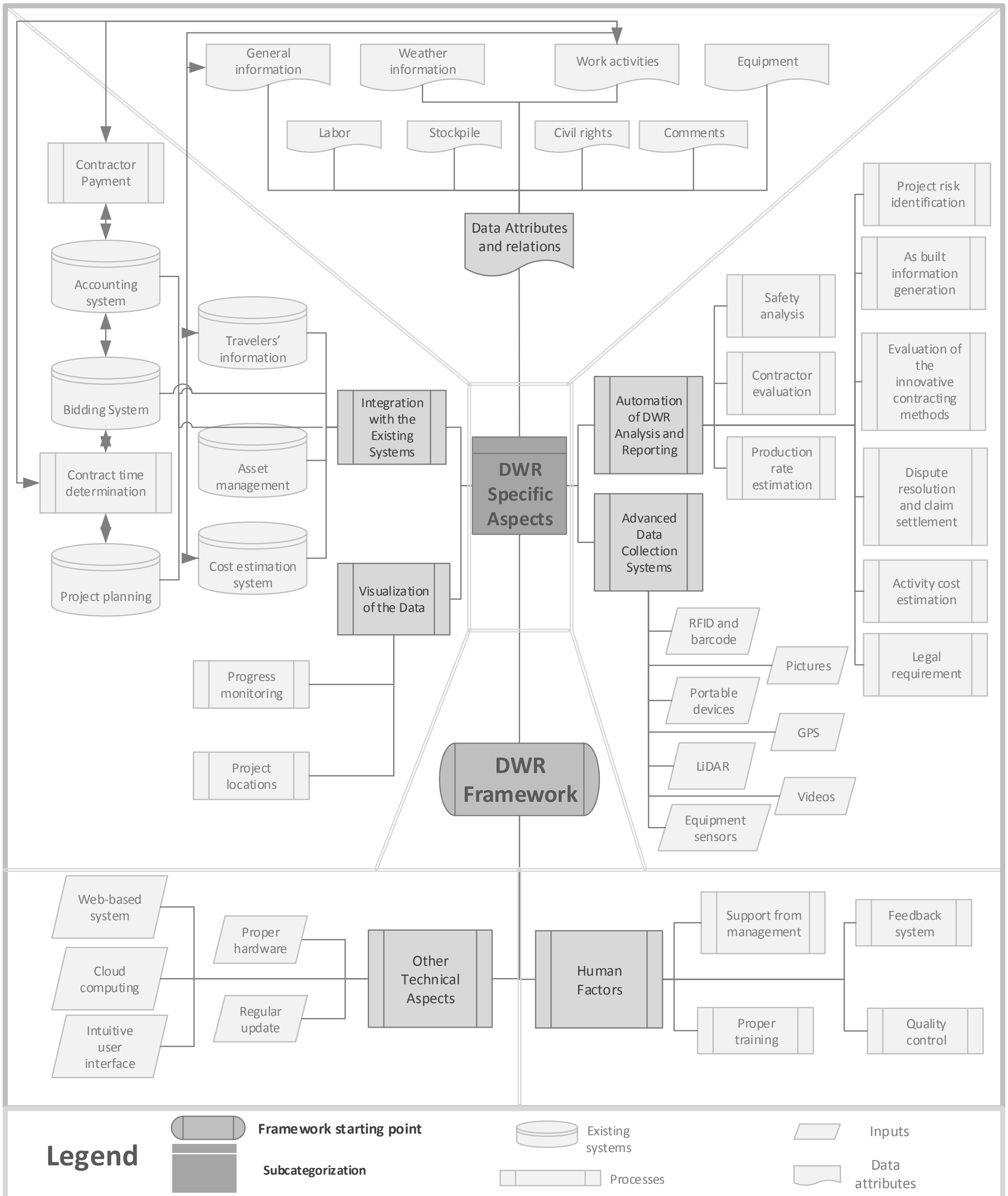


Figure 5.1 Proposed framework for an ideal DWR system

5.1 Data Attributes and Its Relations (Data Model)

A number of digital DWR systems have been developed and utilized by state DOTs since the 1980s. This includes AASHTOWare SiteManager (ASM), AASHTOWare FieldManager (AFM), and Maintaining Assets for Transportation System (MATS). All systems reviewed in this study have similarities in terms of the types of data attributes collected. It was noted that the data attributes collected by most of the state DOTs are fairly comprehensive. All the state DOTs record work activities and weather details in the system. After those two categories of data attributes, various remarks recorded by the state DOTs often contains more valuable information. However, it should be noted that the remark-attributes contains unstructured text data and is often not as easy to automate its analysis. If proper data attributes are recorded while recording remarks, it can be used for applications like problem source classification. Various analyses that can be performed based on each of the data attributes are presented in the "Automation of DWR Analysis and Reporting" section.

In addition to the data attributes, the relationship between the data attributes plays an equally important role in making the data useful for various types of analyses. This study found that while data attributes collected are fairly comprehensive, the data attributes are not linked in the best way in existing DWR systems. In Relational Database Management System (RDBMS), the databases are designed and presented using data models (Jan L. Harrington 2009). The fundamental concept of the data models is described shortly here before presenting the further details about the database design for the proposed DWR system.

5.1.1 Entity-Relation Based DWR Data Model

The Entity-Relation (ER) model is a method to present the data models visually. An entity represents the item about which data is to be stored (Jan L. Harrington 2009). In the case of the DWR system, the work activity is an example of an entity. In the Information Engineering (IE) model, which is one type of ER model, the attributes are presented by a rectangle with its entity listed underneath. For example, the temperature is an example of an attribute describing weather. The attributes have a type and range of values as constrained by its domains. For example, temperature can have an integer (or even numerical) value and hence its domain is in integer values. More specifically, we can limit the length of temperature to, for example, three digits in the RDBMS. The common domain types for data attributes in various systems are presented in the Table 5.2.

Table 5.2 Data attributes and description

Data Attribute Type	Description
CHAR	a fixed-length string
VARCHAR	a variable-length string
INT	an integer
DECIMAL and NUMERIC	real numbers with decimals or fractions
DATE	a date
TIME	a time
DATETIME	The combination of a date and a time
BOOLEAN	a logical value (true or false)
BLOB	a binary file such as image

The entities, its data attributes, and the relationships between the entities can be represented using an ER model. A basic data model for an advanced DWR framework is presented in Figure 5.2. The PK symbol (PK) in the diagram represents a primary key of the entity. The primary key is used to ensure that there is one and only one data record corresponding to a given primary key. The major difference in the proposed model compared to existing DWR systems is that the DWR date and pay items are together used as a primary key. That means, the equipment, labor, and material, for example, are collected for each activities rather than each day only. The benefit, as well as challenges, of utilizing this concept is presented later in the " Automation of DWR Analysis and Reporting" section.

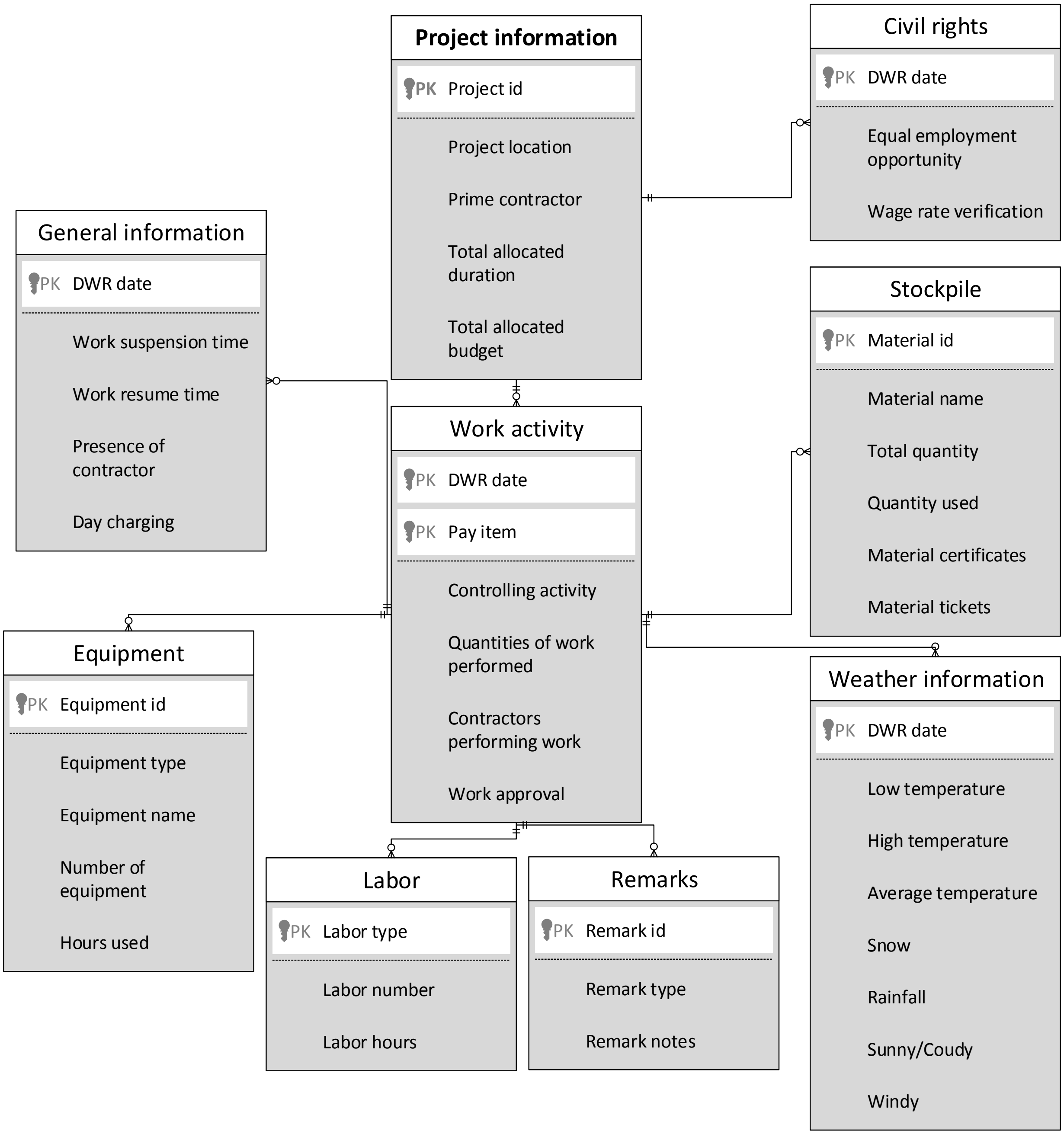


Figure 5.2 IE data model for proposed DWR system

The description of each entity and its attributes along with its ranges is given in Table 5.3.

Table 5.3 Entities, attributes, ranges, and their descriptions for proposed DWR system

Entity	Attribute	Range	Description
Project information			This information is obtained from project information databases and bidding systems.
	Project id	INT	Unique identifier for a project
	Project location	VARCHAR	Can be better represented using coordinates of the project or geospatial file of the project alignment. Current representation is to simplify the diagram.
	Prime contractor	VARCHAR	Prime contractor responsible for completing the project. It can also be represented by a unique id by linking it to another table that has a list of contractors and its IDs.
	Total allocated contract time	INT	Number of days in the contract. Depending on the type of contract, it can also be a final date of completion in which case the range would be DATE.
	Total allocated fund	DECIMAL	The total fund allocated for the project
Civil rights			
	Equal employment opportunity	BOOLEAN	Verification of the equal employment opportunity in field.
	Wage rate verification	BOOLEAN	Verification of the wage rate as mandated by federal, state, and other local statutes in field.
Work activity			Various work activities performed in a particular day.
	DWR date	DATE	Date corresponding to DWR data recording.
	Pay item	INT	Pay item id of the item for which data is recorded.
	Controlling activity	BOOLEAN	Indicates whether the activity was a controlling activity for the day.
	Quantities of work performed	DECIMAL	The quantity of work performed on the day when the DWR data is recorded.
	Contractors performing work	INT	The ID of the prime contractor or subcontractor performing the activity.
	Work approval	BOOLEAN	Indicates whether or not the work performed on the day is approved.
General information			General information recorded in the site.
	DWR date	DATE	The date for which the general information is recorded.
	Work suspension time	TIME	Time when the work is suspended. Various reasons might be the extreme weather, utility relocation delay, etc.

Entity	Attribute	Range	Description
	Work resume time	TIME	Time when the work is resumed.
	Presence of contractor	BOOLEAN	Boolean representing the presence or absence of the contractor on a particular day.
	Day charging	BOOLEAN	Boolean representing whether or not the day was charged. If there is no work performed due to owner caused delay or natural causes, then the day may not be charged.
Equipment			Details of equipment used in the site for a particular activity and date.
	Equipment ID	INT	Unique ID of equipment.
	Equipment type	VARCHAR	Type of the equipment such as excavator, grader, etc. used for a particular activity.
	Equipment name	VARCHAR	Name of the equipment used.
	Number of equipment	INT	Number of equipment used.
	Hours used	NUMERIC	Equipment use hours for a particular activity.
Labor			Details of labors for a particular activity and date.
	Labor type	INT	Type of labor such as supervisor, driver, carpenter.
	Labor number	INT	Number of labors employed corresponding to each labor type for a particular work activity.
	Labor hours	DECIMAL	Labor hours corresponding to each activities.
Stockpile			
	Material ID	INT	Unique ID of materials/items being stockpiled.
	Material name	VARCHAR	Name of the material/item being stockpiled.
	Total quantity	NUMERIC	Total quantity of the material being stockpiled.
	Quantity used	NUMERIC	Total quantity of the material/item used on a particular day.
	Material certificates	BLOB	Certificate of the material used.
	Material tickets	BLOB	Material ticket to verify the total quantity of the material stockpiled.
Weather information			General weather information for the day.
	DWR date	DATE	Date for which weather information is recorded.
	Low temperature	INT	Lowest temperature during the work hours.
	High temperature	INT	Highest temperature during the work hours.
	Average temperature	INT	Average temperature during the work hours. Alternative method to collect the temperature would be to collect continuous temperature using automated electronic system for complete work

Entity	Attribute	Range	Description
			hours.
	Snow	BOOLEAN	Indicates if there was a snow.
	Rainfall	BOOLEAN	Indicates if there was a rainfall.
	Sunny/Cloudy	BOOLEAN	Indicates whether the day was sunny or cloudy.
	Windy	BOOLEAN	Indicates if there was noticeable wind that affected work activities.
Remarks			Various remarks recorded on a particular day.
	Remark ID	INT	Unique ID for a remark. Remark can correspond to a given work activity as well as other aspects such as labor, equipment, delays, etc.
	Remark type	INT	Type of remark such as communication with contractors, safety incidents, significant events, diary, visitors, delays, instructions given to the contractors, force account details, etc.
	Remark notes	VARCHAR	Remark text.

The diagram and charts above present a relatively simplified version of the data model for the proposed DWR system for clarity and understanding. When the actual system is to be developed and employed, the data model will be more complex and should be optimized. For example, the need for using the project ID as one of the keys in the work activity table has not been accounted for in the model presented here.

5.2 Integration with Existing Systems (Interoperability)

The lack of interoperability among different systems used in the construction industry has recently been gaining some attention. As noted by Flintsch and Bryant Jr (2006), agencies utilize a number of databases to record textual and graphic data generated from various divisions within agencies. According to the National Institute of Standards and Technology (NIST (2004)), a huge amount of funds is wasted due to the lack of data interoperability and information sharing by construction stakeholders over a project lifecycle. For instance, in 2002, $15.8 billion was wasted in U.S. capital facilities because of the inadequate data interoperability. This necessitates the need of not only the intra-organizational interoperable systems among project stakeholders, but also the inter-organizational interoperable systems used within an agency. Caltrans (2010) has realized this interoperability issue and the lack of a single reliable system to manage construction project activities. It has recently put forward a request for proposal to develop a new integrated system for DWR and other aspects of construction project management, such as bidding.

Interoperability is defined as “the ability to manage and communicate electronic products and project data between collaborating firms’ and within individual companies’ design, construction, maintenance, and business process systems” (Gallaher et al. 2004). In case of the DWR systems, those systems also need to be connected to other multiple systems used by the state DOTs. When there is a lack of interoperability among those systems, extra effort is required for the data entry and decision makings based on the data. To tackle this interoperability issue, standard construction ontologies can be developed based on existing construction classification systems like OmniClass (Stanford University 2014). Ontologies can be used for finding information easily, to develop and utilize artificial intelligence systems, for system development, and to develop information exchange models.

The development of interoperable and integrated system would ease the information exchange between a DWR system, a project planning system, a design system, an estimation system, an operations and maintenance system, and an accounting system. The result of such interoperable and integrated systems would be the increased ability to make timely data drive decisions with decreased manual efforts. As Iowa DOT project development process manual (2013) states, the continuity of data flow throughout the project development "optimizes the process and promotes fiscal soundness and project credibility."

Table 5.4 presents a list of AASHTOWare products. It can be seen that while ASM and AFM has been licensed by 26 and 7 states respectively, other products, like Project Construction Administration, have been licensed by fewer states. This essentially necessitates the DWR systems to be interoperable with other state specific systems.

Table 5.4 List of AASHTOWare products and users (Source: AASHTO (2014b))

Product	**Number of licensed***
Project SiteManager (ASM)	26
Project FieldManager (AFM)	7
Project BAMS/DSS	38
Project Cost Estimation	12
PES/LAS	28
Project Construction Administration	12
Project Expedite	40
Project Estimator	24
Project SiteXChange	12
Project FieldNet	3
Project TRACER	4
Project Preconstruction	35
Project Civil Rights & Labor	17

*standard license only—excludes evaluation license

The integrated system becomes important not only to ease data analyses, but also to perform detailed data analyses by utilizing data from multiple databases.

A DWR system should also be integrated with a complete document management system. One of the Iowa DOT RCEs noted a lack of the document management system within the AFM and having to rely on another disconnected system. Similarly, pictures and videos taken at the construction site are very important pieces of evidence in case of disputes later. If there are any issues in the quality of the final construction, the pictures and videos taken previously can be used to track back the issues during the early construction phase. In the future, it may even be possible to programmatically analyze the picture and video data.

In ASM, the DWR system is integrated with a change order, extra work, material management, contractor payment, and document attahment systems. In addition, it is also integrated with preconstruction systems. For example, it can import the planning and scheduling details from the Expedite bidding system. Similarly, Utah PDMS also have integrated the vision of combining at least the accounting functions of their DWR system with other systems within PDMS.

5.3 Advanced Data Collection Systems

Information technology has been evolving rapidly. In traffic engineering, they have already initiated research on the concept of connected vehicles (US DOT 2014). The concept of connected vehicles can be considered part of a big movement toward the Machine-to-Machine and the Internet of Things (IoTs). Holler et al. (2014) defines IoTs as a term which includes "a set of technologies, systems, and design principles associated with the emerging wave of Internet-connected things that are based on the physical environment." While the construction industry is one of the largest industries, the use of technology has been limited, as shown by studies. Holler et al. (2014), for example, presented that the construction industry has the least disruption potential in information and communication technology (ITC) and has grown at the slowest rate compared to other large industries (Figure 5.3). Yet, there has been a slow and steady introduction of various technologies in the construction industry and those technologies can be used to automatically collect DWR data. The relevant technologies introduced in the construction industry that can be used to collect DWR data are:

- Picture and video
- Radio Frequency Identification (RFID) and barcode
- Mobile devices and web-based systems
- GPS and GIS
- LiDAR
- Equipment sensors

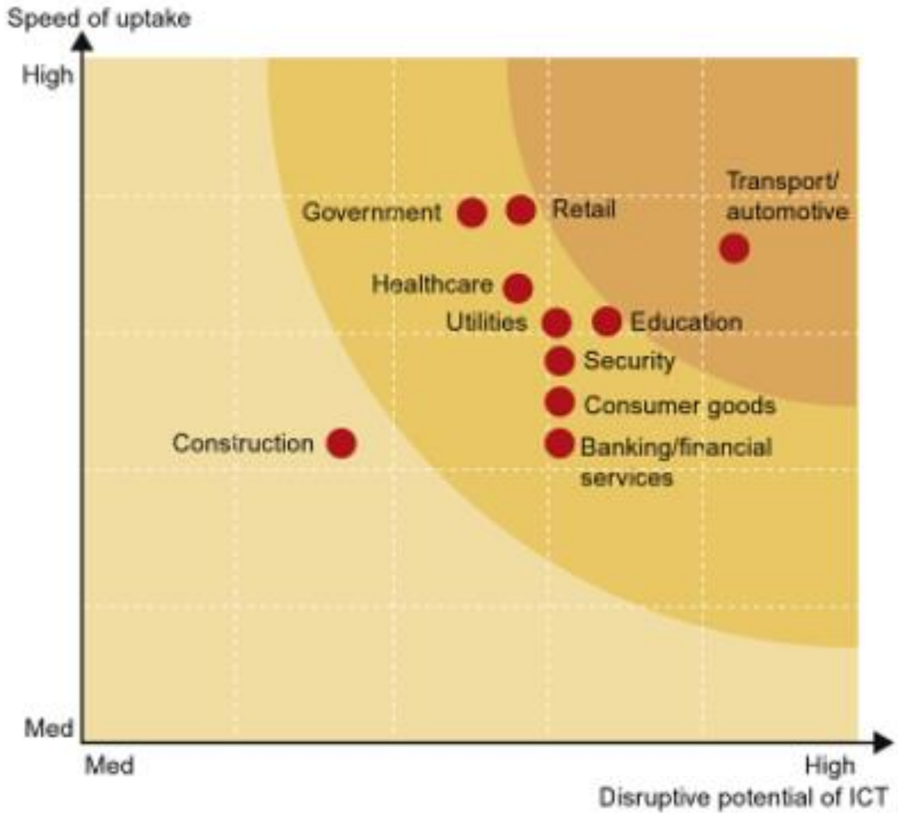


Figure 5.3 Machine-to-Machine disruption potential (Source: (Holler et al. 2014))

The move from the use of paper-based DWR systems to digital DWR systems has enabled the collection of large amounts of digital DWR data. The ability to attach the document, picture, and video has enabled the collection of even more electronic data. A picture can provide much more detail regarding site conditions than remark texts. It is often considered a valuable tool for dispute resolution. Videos can provide even more details. Construction cameras are used very often in vertical construction to collect the visual progress data as well as to use it as evidence in case of disputes. The use of the pictures and video cameras for monitoring construction sites has been studied by Leung et al. (2008). Another study by Abeid et al. (2003) presented the application of images to generate time-lapse photography to monitor construction projects.

Similarly, other data collection technologies like RFID and bar codes can be used for the stockpile management of countable construction items, such as street lights. The applicability of RFID and bar code has been presented in studies like Wang et al. (2007).

The next step in the revolution of the data collection technique is the use of the mobile devices and web-based systems. The construction industry is moving from desktop based DWR systems to the tablet based and Internet based DWR data collection systems. A study by AASHTO found an increasing use of mobile devices among state DOTs and listed construction management as one of the top candidates for mobile software development (AASHTO Subcommittee on Information Systems 2013). Another study by Wisconsin DOT also identified construction inspection in the field as one of the most popular applications of the mobile devices among the state DOTs (Walters and Yeh 2013). State DOTs have been actively involved in developing mobile device-based DWR data collection to ease the data collection. For example, Michigan DOT has been developing Mobile FieldManager, which is the mobile equivalent of desktop-based AFM. Similarly, Valdes-Diaz (2013) is also developing a mobile-based system to automate the DWR data collection in the field. Caltrans (2010) has also put forward a proposal to develop a proof of concept mobile application for its new integrated DWR system. Some of the factors identified by Caltrans (2010) for choosing hardware that are part of the mobile devices are:

- Size and weight,
- Drop resistance,
- Dust resistance,
- Temperature operating range,
- Waterproof,
- Glare-proof,
- Screen resolution,
- Battery life.

In addition to developing the mobile applications, state DOTs are equally interested in developing web-based systems. Caltrans (2010), for example, is developing a new integrated web-based DWR system. Utah DOT uses a web-based PDMS system, which is used by their DWR applications. AASHTO is developing a web-based AASHTOWare Construction Management System that includes the DWR system (AASHTO Subcommittee on Information Systems 2013). The use of the DWR system has the added benefit of connecting to more data collection systems. For example, weather data like rainfall and temperature can be collected from web-sources or using connected weather data collection system installed in the site.

The move from the paper-based system to this tablet and web-based digital DWR system is a big step forward in the direction of using a better data collection system. The move from the computerized digitalized DWR system to the use of even more advanced data collection systems can be another revolutionary shift toward a better future. One state DOT representative imagined a future DWR system in which no data will be needed to be entered manually—the data will automatically be collected by an integrated advanced data collection system. For example, the use of GPS has been studied to automatically monitor highway construction progress (Navon and Shpatnitsky 2005). Another study by Florida DOT noted that over 90% of the FDOT’s pay-items could be located and measured by using the Global Positioning System (GPS) and Global Information System (GIS) technology (Sobanjo 2006). The study also demonstrated the application of the technology for several pay-items and showed increased efficiency and very good accuracy. The GPS/GIS tool took 5 to 8 minutes to measure the quantities while the manual inspection took 40 to 90 minutes. The quantities calculated using GPS/GIS were less than 3% different from the inspector’s calculated quantities. Additionally, the data from Automated Machine Guidance (AMG) also can also provide real-time work progress data.

In the future, just like the smart thermostats for home air conditioning currently being developed by companies including Google, it is likely that systems for collecting not only temperature and rainfall data, but also construction progress data in the construction site will emerge and be able to collect and send the DWR data to a DWR system. The Light Detection and Ranging (LiDAR)-based systems, for example, can scan the stockpiles to compute the material used till the date. Such use of LiDAR has already been demonstrated for the mining industry (Sharma 2013). It may even be possible to analyze the road surface to compute the quantity of work already performed using LiDAR data. In addition, an integration of real-time data from the construction equipment like its location and the task it is currently performing, etc. can be integrated into a DWR system. Current construction equipment manufacturers have already taken some steps toward developing such systems—John Deere Work Site is an example (Deere & Company 2014). The John Deere Work Site is a web-based tool for keeping track of the location of equipment, operator efficiency, and equipment health. Data from such connected equipment can additionally be used to keep track of the total amount of fuel used by the equipment at the construction site. It can then be used to adjust the contractor payments based on fuel usage factors, if any.

The combination of GPS, LiDAR, and camera data also has the potential to be used for generating as-built designs of construction projects. It can be concluded that the construction industry has been moving toward autonomous systems—slowly and steadily.

5.4 Automation of DWR Analysis and Reporting

The study identified a number of applications of the DWR data. The details of those applications and guide for automation is presented in this section. The applications are mostly interrelated with one another—analysis for one application is further used for another application.

This study noted that the reporting is the one of the weakest aspects of current DWR systems. As a result, many state DOTs have developed their own reporting systems based on the DWR data in order to meet their departmental requirements. This is the most important aspect of the DWR framework and is the major focus of the study.

DWR data is one of the most important data collected in a construction project lifecycle. The work activity related data attributes can be used to track the construction progress. Payments can be made based on the progress data. The progress data can be further utilized to generate as-built schedules and costs that can be compared against the as-planned schedule and costs to generate project performance measures. Production rates can be calculated based on the construction activities along with the labor and equipment employed in the site. As-built schedules can be further utilized to generate contract time for future projects. The historical weather data and work days can be used to generate working days and the effect of weather on schedule. Activity costs can be identified using as-built costs, materials used, and labor employed for that particular activity. Resources in the construction sites can be tracked to monitor progress as well as mange the departmental resources for future projects.

Based on the previous project performances and reasons associated with such performances, the project risks for future projects of a similar nature can be identified. Work zone safety data should be collected properly in DWR systems to analyze DWR data with work zone safety data.

The effect of innovative contracting methods can be evaluated using the statistics generated using DWR data such as project performances. Any disputes arising from delays, miscommunications, differing site conditions, etc. can possibly be resolved based on the remarks and work activities collected in the DWR system. DWR data can further be used for quality control, contractor evaluation, asset management, fulfill legal requirements including information sharing to public. It can be used as a feedback system to improve the design and specification of future projects. There is also a possibility of utilizing the text analytics to generate useful information from the DWR remarks data. Finally, the predictive analytics can be integrated in the DWR system to ease the decision making for the RCEs, inspectors, and even upper level management.

5.4.1 Progress Monitoring

Construction projects often face schedule delays. As such, it is necessary to monitor the construction projects so that possible delays can be identified before they impact the whole project schedule. Early detection of possible delays ensures that actions be taken for the timely completion of the project. While the construction contracts usually have liquidated damages for construction delays, state DOTs and contractors often negotiate without charging such damages. As one of the state DOT representatives mentioned, it may be better just to negotiate with the contractor without charging liquidated damage in many cases—“there is a balanced point between trying to charge $2,000 liquidated damage versus the possibility of having to pay $10,000 in court fees.” In addition, even if the state DOT gets the liquidated damage, the delay in construction means that the road users have limited or no access to the road for a longer duration, which is not a desired result. Thus, proper monitoring of the progress is required. The progress monitoring can be on two levels—overall project progress monitoring for all current projects for higher level management personnel and detailed progress monitoring of each project for field personnel. The need for tracking the detailed activity level progress is also documented in Brienza Jr and Hildreth (2007). Project progress can be tracked in three aspects—time, budget, and quantity. Currently, Iowa DOT generates a monthly progress report showing the total dollar amount of works completed under five categories of works: Asphalt Cement Concrete, Portland Cement Concrete, Grading, Bridges & Culvert, and Miscellaneous. The overview of monthly summary sheet (Jan 2014) from the Iowa DOT showed that most of the projects overran their original contract amount. More specifically, the grading job overran its initial contract amount by more than 11% while other types of works showed less than 6% cost growth.

While state DOTs currently keep track of contract time used and cost incurred to the date separately; the combination of those two can give the better insights on the actual progress. In addition, the costs for those activities may vary from the initial budget after a change in the quantities or addition or removal of items. Those three pieces of information (budget, time, and cost) can be used to plot an earned value analysis chart as shown in Figure 5.4. The earned value analysis can present time, budget, and costs parameters for a given project and show the project progress as well as performance over time. It also allows the decision makers to understand the point of time during which potential issues might have started.

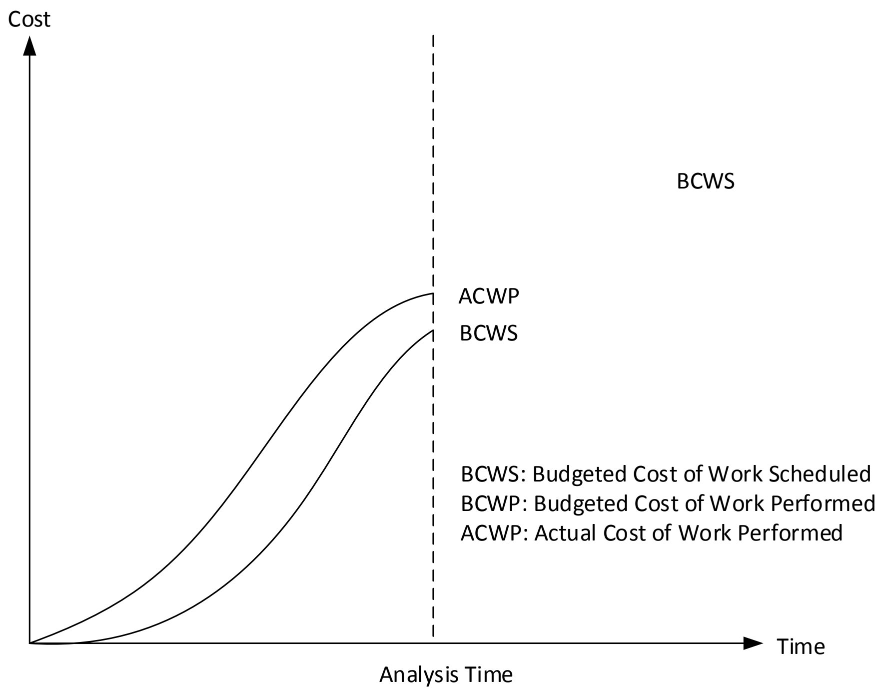


Figure 5.4 Progress and performance monitoring using earned value analysis

Mathematically, the progress in terms of Cost to Date (CTD) at any time t can be calculated as

$$Cost\ to\ Date\ (CTD) = \sum_{t=1}^{m} \sum_{i=1}^{n} \text{cost of each activity} \tag{5.1}$$

where index i represents the item number from 1 to n and index t represents the time of recording the cost data based on the work performed during each recording period and ranges from 1 to m—m being the current time.

In Structured Query Language (SQL), it can be represented with following query:

SELECT SUM (u*q) FROM (SELECT unit_price u from bid_items b, recorded_quantity q from work_activity w WHERE b.projectid='x' and w.projectid='x')

where x is a project ID

To get more detailed information on the particular project, we can compare as-built and as-planned charts, which will be discussed later in another application—"As-Built Information (Schedules, Costs, and Quantities)" section.

The activities generated by grouping the pay-items can be further used to identify major milestones. Monitoring such milestones should also be enabled in a DWR system. The resources, in terms of materials, can also be used to track construction progress. Finally, the development in virtual construction technology will enable the state DOTs to record the progress directly in a 2 or 3 dimensional model of the highway and bridges. Inspectors will be able to record project progress directly in the model that will be updated in real time. It will also be a good visualization tool for the upper level management.

This research identified one of the challenges to monitoring the progress with good details: although the DWR stands for “Daily Work Report,” field data are not necessarily collected every day. As such, the granularity of the progress monitoring can be limited. In addition, the data attributes are collected in a way that limits further automated analysis. However, it should be noted that the benefit of obtaining more granular detail may or may not exceed the corresponding costs. This is discussed further in 5.4.4 Production Rate Estimation section.

5.4.2 Contractor Payment

At the very beginning of project construction, contractors are paid for full or partial mobilization costs (usually up to 10% of the contract amount). After that, the payments are made based on the work progress. The quantities of the work done recorded in the DWR system that is used for progress monitoring is also used for calculating the required amount of payments to the contractors during the end of the payment period. The payment period is usually 15 days or a month. The payments are based on the work done since the last payment was made. While the actual expenses of the contractor form a continuous line, the payments made to the contractor form discrete lines (see Figure 5.5).

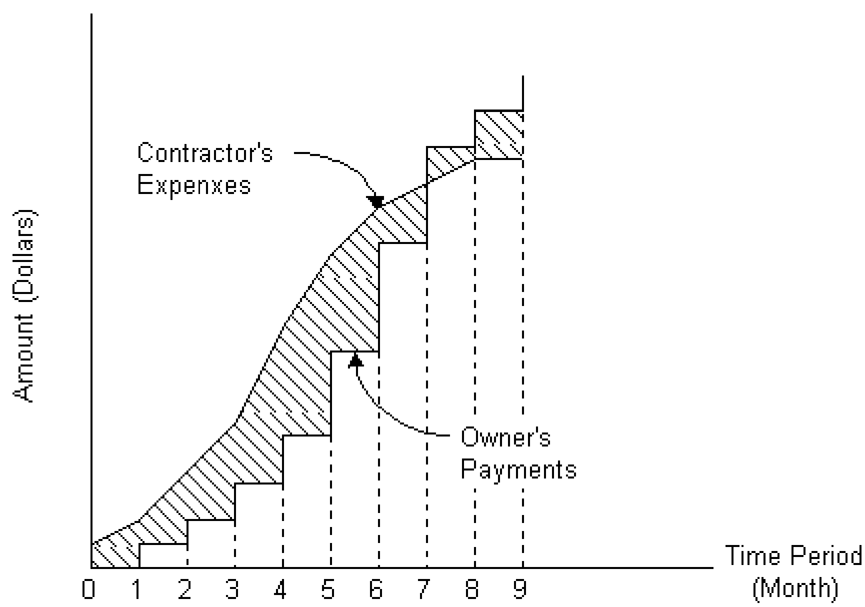


Figure 5.5 Payment and expenses in construction projects (Source: (Hendrickson and Au 2008))

The payment for the contractor can be mathematically presented as

$$Contractor\ Payment\ (CP) = (1 - r) * \sum_{i=1}^{n} \mathrm{q} * \mathrm{u} \tag{5.2}$$

where r is percentage retention, q is quantity of work inspected and approved, u is unit rate of the corresponding item, i is an index representing items from item 1 to item n. Additional consideration should be given to the mobilization that is paid in advance and the retention that will be paid at the end of the project. Similarly, payments can be made in advance for the purchase of stockpiled materials and items. Material tickets can be saved in the DWR system to obtain the quantity of the stockpile purchased and confirm its quality. Also, the quantity adjustment (i.e. quantity overrun or underrun) should also be considered while making payments (i.e. payment should be made for additional approved work and payment should not be made for work that is not performed). The liquidated damages, if any, should be deducted from the total payment.

One more factor that is particularly important when fuel price is volatile is the fuel price adjustment. State DOTs include fuel price adjustment clauses in larger projects. The fuel usage is provided by contractors and payment difference because the change in fuel prices is calculated using local fuel price indexes. The total payment is then adjusted based on that. While the current system of recording the fuel usage is reported manually by the contractors, there is a possibility of utilizing an automatic fuel usage reporting system of equipment to reduce the manual work.

As the payments are made using the financial systems used by the state DOTs, the integration of the system with the financial system is another factor that should be considered for automation of the contractor payment.

5.4.3 As-Built Information (Schedules, Costs, and Quantities)

As-built information is closely related to progress monitoring. Progress monitoring is more focused only on the latest state of the project, while as-built considers progress to the date. As-built is usually used to indicate the final as-built plans. However, the term as-built is used here to indicate the as-built schedules, costs, and quantities. The as-builts represent the actual values for the project, which is often different than corresponding as-planned. As such, it includes the changes in the schedules, costs, and quantities because of the addition or removal of the works, differing site conditions, etc. The as-builts based on the DWR data can be compared against the progress updates provided by the contractor. In addition, the as-built can also be compared against the as-planned schedule, costs, and quantities. It can be used for two major analyses. First is to understand the changes in a particular project in order to identify the reasons behind the changes and their impact. Second is to identify the pattern of changes in order to identify the possible changes in the future projects. The first analysis is discussed in more detail here; the second one is presented later in another application—"Identifying Project Risks."

The costs of the projects increase not only before the construction is started but also after the construction has been started. For that, the state DOTs maintain a contingency fund for each project to complete it with the planned scope (Caltrans 2013b). Additional funds may be provided in special circumstances when the cost growth exceeds the contingency fund and the project completion to planned scopes is very important (e.g. emergency contracts). The RCEs are responsible for managing the construction costs within the current allotment. The RCEs are also responsible for forecasting costs, determining if additional funds will be required, and notifying the upper management if additional funds will be required. The RCEs should not allow the works that requires additional funds to proceed before those funds have been approved and added to the project allotment. For that, RCEs need to continuously update the project contingency balances based on as-built costs. As-built costs are in turn calculated based on as-built quantities recorded in the field using a DWR system.

Just like as-built quantities and costs, as-built schedules are also very important information that can be generated from the DWR data. Kahler (2009) noted that as-builts are generated at the end of projects based on memories. As such, it does not properly reflect the production rates and multiple starts and stops on various activities. The as-builts can be used to evaluate the performances of contractors or to defend against or support delay claims. Virginia, Florida, and Missouri DOTs have used DWR data to automatically generate as-built schedules (Kahler 2009). Not only have the state DOTs, but even contractors have relied upon as-builts generated by the state DOTs to manage the project. Kahler (2012) recommends that dollar amount should be used for preparing as-built schedules. An as-built schedule along with the planned schedule can be used to perform schedule delay analyses. The As-Built But-For (ABBF) schedule delay analysis, for example, calculates the non-compensable contractor-caused delays by removing the compensable owner-caused delays (Long 2013). Other delay impact analysis methods include the fuzzy logic method, global impact technique, net impact technique, as-planned method, as-built (or traditional) method, modified as-built method (or time impact analysis), collapsed as-built method, snapshot or window method, and contemporaneous period analysis (Oliveros and Fayek 2005).

Russel et al. (1993) presented some of the reasons for the delays:

- Weather,
- Ground conditions,
- Design problems,
- Accidents,
- Testing results,
- Equipment issues,
- Delayed proceeding activity,
- Utility relocation,
- Vandalism, etc.

Those categories of delay causes can be grouped into contractor-caused, owner-caused, and third party-caused delays for further analysis. Henschel & Hildreth (2007) provided details for contemporaneous and retrospective schedule delay impact analyses. In the contemporaneous schedule delay impact analysis, the impacts of the delays are assessed as soon as the delay occurs. This methodology is different from the retrospective schedule delay impact analysis in which the impact of delays is assessed after the completion of the project. The study provided delay impact analysis based on as-built schedule, baseline schedule, and general delay data. The methodologies presented in the study are Global Impact, Net Impact, Adjusted As-Planned CPM, Adjusted As-Built CPM, Collapsed As-Built (But-For) Schedule, Impacted Updated CPM, Modification Impact Analysis, and Time Impact Analysis. The Global impact approach, simplest of all, utilized the individual delays and added up the delays irrespective of the schedule logics to calculate the overall impact. Such methodology is very simple and does not take account of the concurrency of the activities or critical path. Thus, it is universally rejected by the industry. However, if the baseline schedule and/or as-built to date schedule are not available, it is the only available method. Justification by argument and global impact approach might be the method used by state DOTs that do not have well-developed impact analysis methodologies. If the required data, such as start and end date of each activities, are collected, it can be used for more precise delay impact analysis using methodologies like Adjusted As-Built CPM, Collapsed As-Built But-For Schedule, etc.

Similarly, if the start and stop times of the pay-item activities are collected in the DWR system, the historical sequences of activities can be identified automatically. This can then be used to automatically generate the schedules for future projects. Tauscher et al. (2014) have developed and demonstrated such framework for automatically generating the construction sequence for vertical construction.

The benefits of as-built schedules as noted by various studies are (Avalon 2014; Vandersluis 2013):

- Comparison against the baseline schedule to monitor the progress,
- Analyzing the impact of the schedule delays or justifying the delays claims,
- Variation in the output over time, location, and contractors,
- Identification of the causes of the variation of the output,
- Calculating the time and effort invested for a particular activity,
- Generating the overview of what happened and when,
- Evidence of the work in case of disputes,
- Calculating production rates,
- Identifying the out of sequence activities,
- Identifying the person and/or contractor performing the tasks,
- Identifying the activities that required excessive duration.

Similar to progress monitoring, as-built can be developed based on quantity, cost, and time.

The application of the five steps in Knowledge Discovery in Databases (KDD) (Fayyad, Piatetsky-Shapiro, and Smyth 1996) in DWR data to develop as-built production rate and as-built schedule is presented in Figure 5.6. As presented in the figure, the original DWR data and as-planned or original schedule are the required data for the analysis. The date, pay-items, and original schedule are then selected from the database, which is preprocessed to develop a group of pay-items to form activities in the original schedule. After that, the data is transformed to develop an as-built schedule and then compared against the as-planned schedule to evaluate the schedule performance. Now, instead of just comparing this data with the planned schedule, the data can be further analyzed using the predictive analytics based on varieties of factors such as contractors performing the work, resources being employed for the project, project site characteristics, project type, weather, etc. The predicted completion date from such analysis can serve as a warning sign for possible issues with the project progress.

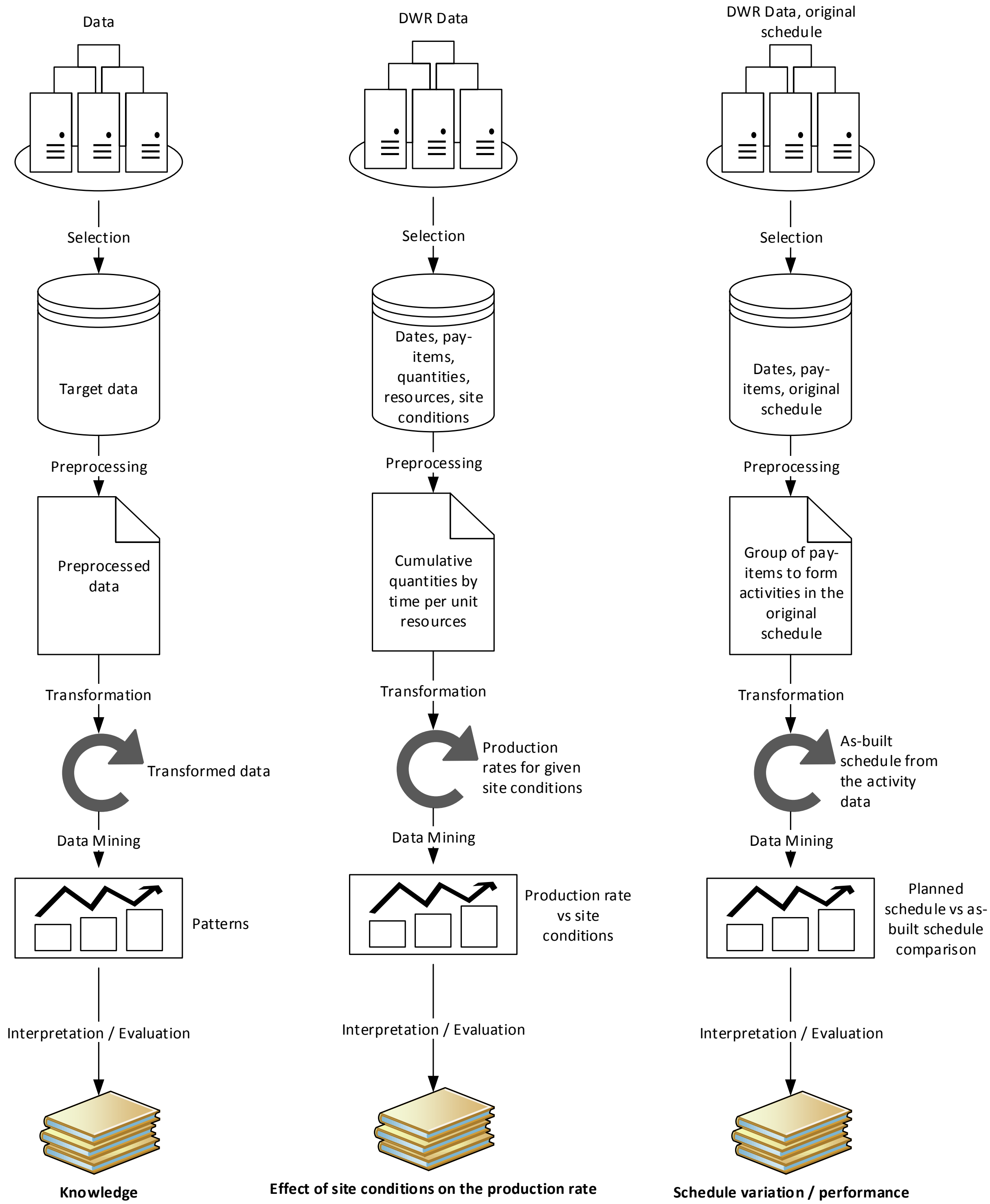


Figure 5.6 Application of KDD process on DWR data

5.4.4 Production Rate Estimation

A good estimate of production rates increases managerial efficiency, reduces delays in completion of a project on time, and lowers the overall project costs (Jeong and Woldesenbet 2010). The DWR data can be actively used for estimating the historical production rates that can be used for estimating the contract times for future projects. The current level of data collected by state DOTs can be used to calculate the production rate per day using the equation (5.3).

$$Production\ Rate\ (PR) = \frac{Quantity\ of\ work\ (q)}{Total\ number\ of\ days\ (d)} \tag{5.3}$$

It may be noted that the state DOTs may not necessarily collect the data every day, which will give some error in the estimation. But, that should still give reasonably accurate production rates. Jeong and Woldesenbet (2010) used the DWR data along with soil data and Average Annual Daily Traffic (AADT) data to predict reasonably accurate production rates of excavation, borrow, aggregate base, sub-grade modification, etc. based on the environmental, geographical, and project site conditions. There are additional factors that change the productivity. As one of the state DOT representatives mentioned, the equipment and labor hours or efforts required for sliver fill on a roadway widening project would be different than the sliver fill on a roadway and bridge embankment on a new alignment. Some of those factors may require engineering judgment unless such data are also recorded in the system using nominal attributes.

State DOTs also collect the number of construction workers working every day without associating it with a specific task. The reason for this is that the DWR systems were developed with the objective of monitoring the progress and making payments rather than for generating historical production rates and other performance measures (Rich 2006). This drastically limits the analyses that can be performed using the DWR data. For example, when multiple activities are performed in a given day by the same crew, the production rate calculations can become inaccurate if crew hours spent for each activities were not recorded. Hence, for automating the accurate production rate calculation, it is recommended that the DWR data be collected with activity on top and linking the labor and equipment hours with it as opposed to the current system of collecting DWR data where data is collected in relation with a day only. The Figure 5.7 shows the proposed adjustment along with its benefits. Both of the methods can be used to generate activity sequencing and possibly contractor evaluations based on the time taken by the contractor to complete the work (for example, whether the contractor completed the work within time or not), but the activity-on-top gives the added benefit of calculating accurate production rates.

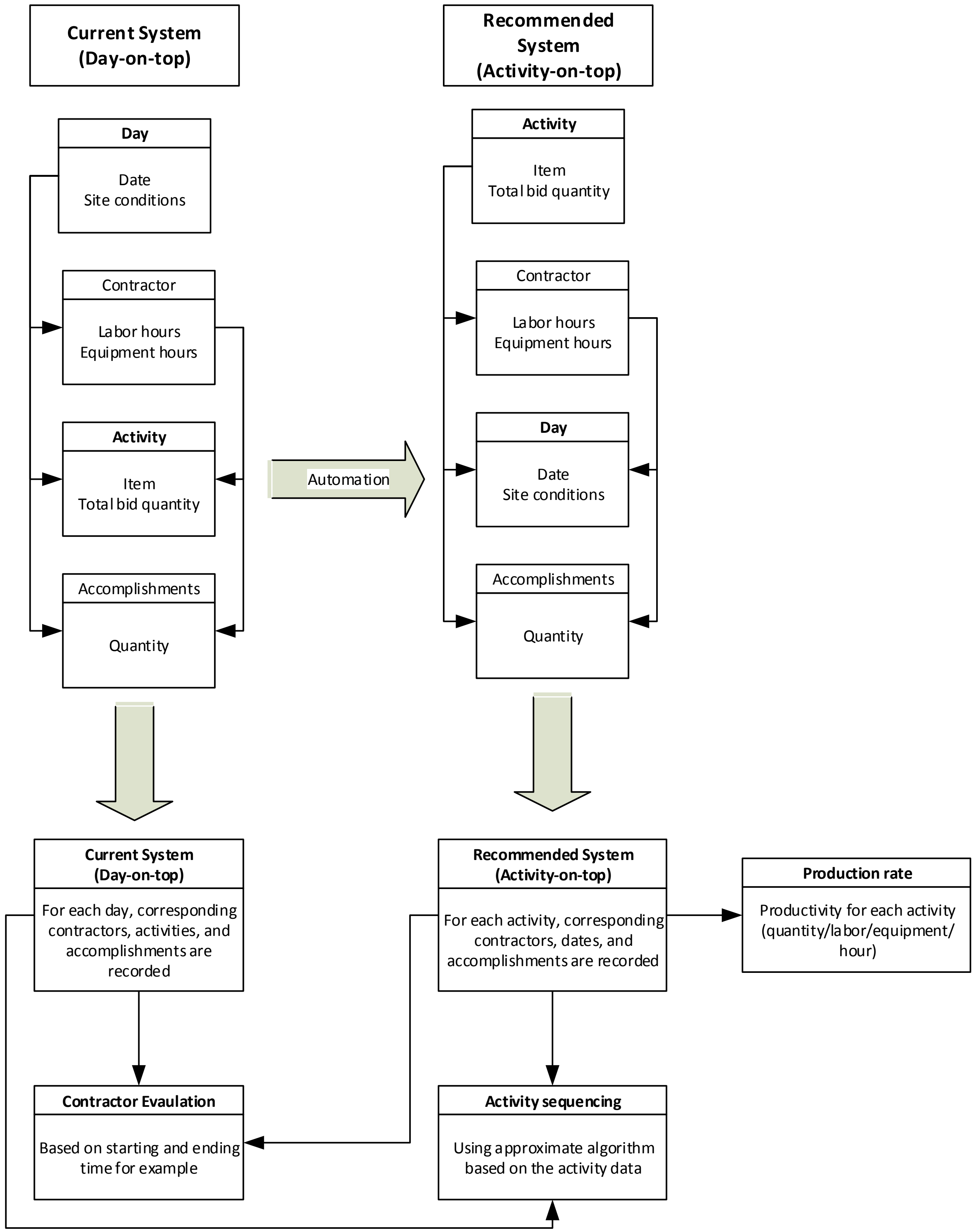


Figure 5.7 Day-on-top to activity-on-top transition of DWR data collection and its benefits

This method would take slightly more time to collect the data. However, the researchers believe that, if the state DOTs are already collecting the DWR data every day and also collecting the labor and equipment hours alongside, the extra amount of time required will be negligible. There is no additional data required to be collected using this system—it is rather just an added link to the system. Caltrans (2013a) collects the equipment and labor hour data for each activity, which can be used for this purpose. However, Caltrans utilizes a paper-based DWR system, which becomes an issue to automate such calculations. If the state DOTs are not collecting one or more of the data (quantity, labor hour, equipment hour), there will be a need to collect noticeably more amounts of data. In either case, it would be more useful to track the detailed data for major controlling activities rather than all items, including the minor items (see for example the major bid items identified by Rich (2006) which is presented in Table 5.5). The Pareto principle can be followed to identify the 20% major pay-items that are more important in terms of costs, possible issues, schedule, etc. The use of advanced data collection systems (equipment sensors, RFID tags, bar codes, etc.) can be used to automate and ease some of the detailed data collections such as equipment hours, material uses, etc. that are required for production rate calculation.

Table 5.5 Major or driving bid items example (Source: Rich (2006))

Bid Item No.	Description
00100	MOBILIZATION
00125	GRADING
00140	BORROW EXCAVATION
00591	COMB. UNDERDRAIN CD-2
01150	15" PIPE
01240	24" PIPE
10128	AGGR. BASE MATL. TY. I NO. 21B
10607	ASPHALT CONCRETE TY. SM-12.5A
10612	ASPHALT CONCRETE BASE COURSE TY. BM-25.
13320	GUARDRAIL GR-2
13331	RAD. GUARDRAIL GR-2
60404	CONCRETE CLASS A4
60490	BRIDGE DECK GROOVING
61812	STR.STEEL PLATE GIRDER ASTM A709 GRADE
62015	RAILING, KANSAS CORRAL
64011	STRUCTURE EXCAVATION
64110	STEEL PILES 10"
65013	CONCRETE CLASS A3
66120	COFFERDAM
66239	DRY RIPRAP CL.II 38"
67900	NS DISM. & REM. EXIST. STR. DISM.& REM.

The benefit-cost of those methods, which may vary from state to state, should be evaluated before implementing this change. Additionally, the state DOTs can also utilize the force account data used for extra works for calculating the production rates with more accuracy. It may be noted that, the production rates for activities completed under force account may be slightly different than the production rates for the activities included in the contract.

If even more detailed data is to be collected, time of the beginning of work, time when the work was paused, resumed, and stopped can be collected. This level of detail though might be more than required, but can eventually become collectible if automated digital data collection systems are implemented. For example, the time when equipment was running and working can possibly be tracked and sent to the DWR system automatically in future which will indicate the time when work started, paused, ran, and stopped. The detailed level of data can be used to explain the variations in the production rates based on the number of workers, equipment, hours, etc. that cannot be explained when only quantity of work completed every day is collected. The calculated production rates can be further used to compare the production rates with labor-intensive versus equipment-intensive construction methods as well as production rates when different units of equipment are used. It may be used to identify the best combination of the labor and equipment combination. Further, it may be used to identify the potential cost differences when performing work with different methods. This can explain some of the variations in the bid unit prices which may otherwise be noted as outlier or unbalanced bidding. If the cost variations cannot be explained even with the DWR data, it can then be identified as unbalanced bidding. The trend of unbalanced bidding in the past can be used to identify contractors who may possibly use the unbalanced bidding technique in the future.

State DOTs use the production rates of a number of items to determine contract times for their projects. Iowa DOT, for example, has daily production rates of 83 bid items (IaDOT 2012). However, those production rates are not based on the DWR data and are updated manually based on the experiences as per one of the Iowa DOT representatives. Thus, if DWR data is collected properly, such data can be updated automatically.

5.4.5 Contract Time Determination

While determining the contract time, there should be a balanced approach to keep the contract time long enough to allow smaller contractors to compete for the project and short enough to minimize the road user inconvenience (IaDOT 2012). The production rate calculated based on equipment and labor data can be used to estimate the duration and even costs of future projects. An Alabama state DOT engineer stated that they review similar projects completed in the past to determine the timeline for the new projects.

5.4.6 Impacts of Weather Events

While determining contract time, it is necessary not only to consider the daily productivity, location, and project type, but also the effect of weather. Especially in the case of contracts with late completion dates, weather effect becomes more important. Weather events such as heavy rain, snow storms, and severe wind can delay construction projects, resulting in deviation from the original schedule. For example, Pennsylvania DOT (2011) has weather-related specifications, such as “do not place bituminous paving mixtures when surfaces are wet or when the air or surface temperature is 40F or lower.” In the case of the contracts with the number of working days, the working days will not be charged to the contractors when such valid weather events are presented. However, the expected completion date of the project will change. Such changes need to be identified by the state DOTs in advance to manage the time of their inspectors accordingly. For example, the number of concurrent projects can increase because of the delays of the previous project, resulting in an increased work load for the inspectors.

In case of schedule driven contracts with the late completion dates, careful consideration of the weather delays should be considered to ensure that the contractors will have reasonable time to complete the project. Historical DWR data contains attributes about the day charging and the weather information of the corresponding day. This can be used to calculate the number of working days for each month or season. Alabama DOT (2013) installs rain gauges to record the rainfall data in the construction site so that it can be used to identify the actual delays because of the rainfall, with other delays including the contractor-caused delays. In Vermont DOT, the weather predictions are used not only to inform the travelers but also to allow the maintenance crew to proactively rather than reactively act for the maintenance activities (White and Portalupi 2013).

South Dakota DOT conducted a study to prepare weather charts quantifying the effect of weather on the construction projects with the objectives of reducing disputes, claims, time extension requests, and the costs (Kenner et al. 1998). The DOT has spent significant time and effort in the past to settle disputes resulting from the weather delays. Charts were developed and validated using the interview, historical DWR data, and historical precipitation data. Similar studies have been conducted for Texas and North Carolina DOTs (Sims, Ford, and Patterson 2014; Woods 2008). Those studies used the monthly average precipitation, temperature, wind speed, and number of weekend days and holidays per month for developing the models.

In addition, weather can affect productivity, as studied by a number of researchers (Apipattanavis et al. 2010; Apipattanavis et al. 2010; El-Rayes and Moselhi 2001; Kenner et al. 1998; Nguyen et al. 2010; Shahin, AbouRizk, and Mohamed 2011; Woods 2008). El-Rayes & Moselhi (2001) studied the impact of rainfall on the productivity of highway construction activities such as earthmoving, construction of base courses, construction of drainage layers, and paving. The model developed in the study can be used to analyze the weather-related delays and claims. Apipattanavis et al. (2010) developed a semi-parametric weather generator (SWG) model to predict the schedule variation resulting from the weather events and expected to reduce construction claims because of the weather events. The weather data can be used not only to determine the contract time before construction begins, but also to give time extensions to the contractors once the construction has already started.

5.4.7 Activity Cost Estimation

State DOTs rely heavily on the unit prices from historical bid items to estimate the costs for future items. It is common not only to have varying unit prices for the same items in different projects, but also to have widely varying unit prices in the bids for the same items for the same projects. After state DOTs receive the bids for projects, they analyze the bids using the line item profiles to see the variation in the unit prices for important bid items. As per the discussion with one of the Iowa DOT personnel, more often than not, they have no idea as to why the unit prices fluctuate so much in different bids for the same bid items. As such, it would be challenging to incorporate such fluctuations in the unit prices during the cost estimation phases. Some of the factors that are responsible for such fluctuations can be explained by the DWR data. For example, even though the quantities are same for the bid items, it may require varying amounts of effort for the same activity because of other conditions. For example, even excavation of the same class of earthwork might require different amounts of effort because of fluctuations in local conditions, weather conditions, site conditions, traffic conditions, etc. Those efforts will be recorded in a DWR system. Thus, the activity costs can be estimated from contractors' perspectives, i.e. calculating the material costs, labor costs (labor hours * hourly wage rates), and equipment costs (equipment hours * hourly rental costs). The level of detailed data collected by Caltrans (2013a) should be sufficient to make such computations. So the production rates calculated can not only be used to determine the schedule, but also to determine the costs from another perspective. This can then be used to explain the variations of unit prices in different projects and understand the contractor's techniques of distributing overhead and profits on bid items. If the variations cannot be explained by it, another reason might just be the number of manipulation tricks used by the contractors.

5.4.8 Resources on Construction Site

The DWR data can be used to keep track of the resources employed in the construction site. The major resources to be tracked include the contractors, contractors' labors, contractors' equipment, materials used, and owner's representatives. Such data can be used to calculate the amount of various materials consumed in highway and bridge construction. It can be used to calculate how many jobs were created or maintained by the DOTs' construction activities. The equipment details can be used to estimate the environmental effect of the equipment. For example, a study by Truitt (2009) showed that the construction industry is the third most contributing industry for greenhouse gas emission. More detailed analysis and the contribution from the equipment usages in the construction site may be analyzed. And if the contribution from construction equipment is significant, further research may be conducted to reduce such impacts. For example, according to one study, a systematic reduction of equipment idle time can contribute to reducing the environmental impact from construction equipment as well as increase its productivity (Akhavian and Behzadan 2013). Further, the amount of fuel consumption (which is much related to the amount of emission) can be studied against the amount of work to see if the environmental impact resulting from the same quantity of work has been decreasing over time or has remained constant.

The DOT can also utilize their own inspector and RCEs' time and project assignments to plan the resource allocation or possible need for additional employees to handle the work load properly. It is not uncommon that the inspectors have to monitor multiple construction sites of smaller projects. It may be possible to reduce concurrent work load for the inspectors by optimizing the project sequences as well as by utilizing the risk adjusted project schedules to reduce the unexpected project overlaps.

5.4.9 Identifying Project Risks

Construction projects usually include changes in scope, such as the addition and removal of work items, changes in the quantities of the work, etc. The original planned information is recorded in the bid and contract documents while the changes are noted in the site and are recorded in the construction management systems based on the DWR data. The pattern of changes in those change orders with the project characteristics such as project type, location, size, etc. can be explored using association rule mining. The association rules are defined in terms of minimum support, confidence, and lift. Minimum support is the percentage of records within the dataset that are relevant; a confidence is a percentage of relevant record in which the given association rule is valid; and the lift is the increase in the validity of associations within the relevant dataset compared to the complete dataset. More details on those concepts can be found in Han and Kamber (2011). A hypothetical scenario is presented here to clarify this concept of the association rule mining. Let's consider a state DOT that let bids for 600 large projects in 2013. Out of these 600 projects, 200 projects were large bridges and the remaining 400 projects were large pavement projects. Now, the changes in the quantities of each bid item were calculated to identify any specific pattern in the quantity changes. The association mining rules like Apriori will generate a large number of possible associations, which can be used to generate some conclusions. For example, it may be identified that the quantities of excavation grew by more than 10% of the original quantity when the project was a large pavement project in district 'A.' If the number of large pavement projects in district 'A' was 45 and the number of those projects with more than 10% quantity overrun is 40, then the support will be 12.5% (50/400) and its support will be 88.9% (40/45). Now, if the overall percentage of projects in which the excavation quantity overrun by more than 10% is 50%, then the lift of the association rule would be 1.8 (88.9/50) which is higher than 1%. What it means is the given association rule has more percentage of projects with higher cost overruns than the overall projects and hence the given rule is valid. The DWR data and the CMS data provide enormous opportunities to explore the association rules like this. Once those association rules with high confidence and high lifts are identified, proper actions can be taken to limit the changes. For example, in a previous case, the reason behind high quantity overrun in that particular district for the particular type of projects can be identified. The findings can then be used in the later projects to improve the quantity estimations. The example provided here is related to the quantity overruns, but the same concept can be used for schedule overruns (or delays) as well as cost overruns.

5.4.10 Work Zone Safety Analysis

In 2010, there were 87,606 crashes in work zones in the U.S.—out of which 30% were injury crashes (FHWA 2014). The work zone crashes may occur as a result of driver inattention or because of improper work zone setups. The crashes can result in property damages, injuries, and even fatalities. State DOTs keep record of such injuries in the construction work zones. State DOTs have relied heavily on the crash data collected by law enforcement agencies (Bourne et al. 2010). However, such practices have resulted in a lag time between the crash and the time that the data is available for analysis to DOTs by as much as a year. In some cases, DOT inspectors also collect some crash data providing details especially regarding the traffic controls used in the work zone. For example, Iowa DOT (2003) uses a checklist to collect traffic control data such as:

- Flagger manual compliance by the personnel,
- Presence of warning signs that are spaced correctly,
- Acceptable condition of the devices,
- Correct road closure time.

If the traffic control was not maintained properly, it will be noted down in the checklist and the contractor will be notified. When such issues are noted by the contractor, they should act quickly to ensure the safety of the travelers. An integrated web-based DWR system can be used to promptly notify the contractors so that they would take required actions in due time. Currently, the above mentioned checklist data are collected in a different system such as a paper-based form, which makes it challenging to integrate the data with the data collected in the DWR system for analysis. Those data collections can be integrated into DWR systems so that safety analysts can generate actionable insights from the incident data easily. In addition to that, structured details of other work zone incidents should be collected in the integrated system. The current DWR system lacks the structural attributes to collect such information and all the details are collected in remarks or in a different system. Some of the data attributes that can be collected would be the number of injuries, types of injuries, and types of safety rule violations leading to the injury.

The historical crash data can then be analyzed to identify any pattern in the work zone crashes. For example, the crashes might occur more frequently when a particular type of traffic control is used or when the project is in certain phase of completion. Based on that, the traffic control methodologies can be improved for future projects.

5.4.11 Evaluating Effects of Innovative Contracting Methods in Project Performances

There are multiple factors ranging from project type, project location, weather, contractor, etc. that affect the project performances. The use of the innovative contracting methods is another factor that can affect the project performances—for example, the A+B contracting method in which both the bid amount and time of completion of the contract is likely to reduce the construction time. It may be useful to know how the projects are accelerated for such contracting methods. For example, the use of more resources may be one of the possible methods, but the application of innovative construction technologies and use of different construction sequencings can also be the reasons behind that. It may also be possible to identify the use of different construction sequencing and modern technologies using the DWR data. Another question that can be answered using the DWR data is the rate of acceptance and rejection of the works when using such innovative contracting methods, i.e. the relationship between the quality control and the contracting methods.

Similarly, if project performances of a particular type of project were better when a certain type of contracting method was used, the contracting method can be used in upcoming projects of the same type.

5.4.12 Claims and Dispute Resolution

Construction claims and disputes are prevalent and is a major problem in the construction industry (Yates and Epstein 2006). Lavigne (1993) defines a claim as "a formal contractual procedure used to review contract disputes between the contracting parties." Disputes are "the claims that remain protested after completing the claims procedure." Some of the causes of claims include delay in access to the site, delay in getting required permits, defects in plans or specifications, design changes, the addition or removal of scope, suspension of works, defective works, schedule delay, differing site conditions, unusual weather, labor disputes, etc. Those reasons can be categorized as contractor-caused, owner-caused, or caused by third party and nature. While the contractor-caused delays and changes will not be compensated by the owner, the owner-caused delays and changes will be claimed by the contractor for the compensation. As such, the first step in settling a claim would be to identify the party that caused the reason for the claim. Alabama DOT (2013) states that enough details should be collected in the DWR system so that it can be used as a legal instrument that will substantiate a just claim or disapprove an unjust one. The DOT considers the DWR data as the most important data collected by the project engineers and his staffs. DWR data, such as pay item quantities and quality inspections along with photographs and/or videos, plays a key role in dispute resolution. Similarly, the specific instruction given to the contractor, contractors activities, discussion with the contractors, time charges, compliance or violation with safety requirements, remarks about no work done, reason for delays, and special site conditions can also become a vital piece of information for resolving disputes.

In the case of claims resulting from owner-caused changes, such as addition of work items, state DOTs can utilize the historical DWR data, labor productivity, change orders, etc. to calculate the appropriate compensation. Caltrans believes that it has ended up paying more than the required amount for construction claims because of the lack of automation to quickly get the reasonable rate for additional work activities (Caltrans 2010). As such, Caltrans's objectives for developing the new DWR system include reduction of payout rates for construction claims, reduction of cost of research associated with construction claims, and reducing arbitration awards and settlements by improving access to data by legal and expert witness staff.

Similarly, DWR data is also very important when claims for compensations are made for delays (Ellis and Thomas 2001). The determination of owner-caused delays is not straightforward when using basic bar chart schedules, which is commonly used in the state DOTs (Ellis and Thomas 2001). Analyses are required to calculate compensable owner-caused delays based on the DWR data by deducting delays caused by the contractor, third-party, and nature from the total delay. The delay analysis should be done by identifying the controlling items of work noting that an item that was controlling in the planned schedule may not remain as a controlling item on the as-built schedule. Controlling items are the activities—the delay of which can potentially delay the contract completion (Ellis and Thomas 2001). State DOTs have a mechanism for notifying the DOT of the potential claims before the claim is made (see for example Caltrans (2008)). Such a system should also be integrated into the DWR systems to make decisions regarding claims. When such potential claims for additional works are noticed, the state DOTs may collect more detailed data on the DWR system regarding the quantity of work, material, equipment and labor hours in a forced account format that can be used later to calculate the appropriate compensation.

The compensation should be calculated for idle equipment and labor, and loss of productivity (Ellis and Thomas 2001). To calculate the loss of productivity, the standard production rates should be calculated beforehand based on the DWR data for previous projects. Additional indirect costs may also be added in the costs such as home office staff salaries, home office rental expenses, home office utilities costs, legal costs, accounting costs, and professional licensing costs (Ellis and Thomas 2001).

5.4.13 Quality Control

In the DWR systems, data is collected regarding the acceptance of the work performed by the contractors before making the payments to the contractors. While some tests such as soundness of the grouted riprap, abrasion of fine aggregate, etc. may be conducted on the laboratory, others are based on visual inspections and field tests. Oregon DOT, for example, conducts the visual inspection of the aggregate backfill, aggregate base, aggregate for ditch lining, fill material and riprap gradation, filter blanket, and compaction to ensure its quality (Oregon DOT 2003). This information can be recorded in the DWR system to ensure that the quality of the final product in a particular location meets the requirement. If the work needs improvement, the contractors may be notified in due time regarding the issue.

5.4.14 Contractor Evaluation

The work quality can be analyzed against the contractors to evaluate the contractors. Further, quality-based contractor evaluation can be used to give preferences to the contractors based on their past performances. While, giving preferences to the contractor may seem unfair, the cost of the projects that may need additional work is likely to increase. As such, if a highly rated contractor has a slightly higher bid, the final costs may be lower than if the lowest bidder was selected. In addition, the DWR system can be developed further to become a centralized communication system between the personnel from the contractor and the DOT. The issues noted may be posted in that system where the contractors can add the actions taken by them after the issue has been communicated (Table 5.6). The response time from the posting of the new issue to the action taken to solve the issue can be used as a factor for the contractor evaluation. Similarly, the number of issues that are registered in the system and the number of issues that are taken care of properly can be used as another factor for the contractor evaluation. Some of such issues may be, the quality control issue, traffic control devices that were disturbed by traffic (e.g. missing cones, etc.), absence of the contractor during scheduled work, etc. The system can be used as a substitution or addition to the e-mail communication system. The benefit of using such a system would be that all the relevant communication about the project can be obtained in a single place. It could possibly reduce the number of issues that could arise because of proper communications.

Table 5.6 Sample post in web-based centralized communication system

Solved (?)	Date	Description	Post by
✓	5/7/2014: 10:30AM	Traffic cones missing—possibility of traffic incidents	DOT
	5/7/2014: 10:50AM	Cones rearranged to ensure smooth traffic	Contractor
	5/7/2014: 10:60AM	Rearrangement verified	DOT

Currently, the contractor evaluation forms are filled by the inspectors and RCEs after the completion of the projects based on memories. Analysis of work quality as well as the project performances generated or recorded in the system can be used as one of the factors to automatically evaluate contractors' performances. Similar to the work quality mentioned above, an analysis can also be performed to identify the contractors who successfully completed most of the projects within the contract time. In addition, information such as the number of days a contractor did not show up, the number of projects that were completed on time despite the absence of contractors on some days, etc. can be tracked based on the data collected in the DWR system. Thus, the contractor evaluation can also be semi-automated. Some subjective inputs will still be required for detailed evaluations. For example, the change in cost and schedule can be associated with a valid reason and not a result of a contractor's performance. The performance record can be used to decide whether a particular contractor should be allowed to bid for a given project. In addition, contractors' evaluations can be used to identify the top choices when emergency projects are to be started without going through the usual competitive bidding process. Some of the items used to rate contractors in Iowa DOT that can be automated include the completion on schedule, quality of finished product, administrative and general project safety, and equipment on the project.

5.4.15 Asset Management

FHWA (1999) defines asset management as "a systematic process of maintaining, upgrading, and operating physical assets cost-effectively." The definition of asset management has since evolved to "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable costs" (U.S. Government Printing Office 2012). The DWR data collected in the field such as various maintenance activities performed in a given locations becomes an important piece of data to improve asset management practices. The DWR data, for example, can be used to calculate the amount of asphalt used in a particular stretch of highways or the number of labor hours employed to maintain the stretch. Maintaining Assets for Transportation Systems (MATS) used by Vermont, New Hampshire, and Maine DOTs has integrated the asset management functionality and DWR functionality in a single application (Rogers 2013). Such system allow for the transfer of data from a DWR system to the main asset management system directly.

5.4.16 Legal Requirements

There are a number of state and federal requirements such as nondiscrimination (e.g. Equal Employment Opportunity (EEO)), Davis-Bacon related acts and provisions (e.g. minimum wages, payrolls, and basic records), and contract work hours and safety acts (e.g. overtime requirements) (Federal Highway Administration 2012). The contractors are contractually obligated to meet those requirements and state DOTs have a responsibility to verify that those requirements are met as per the contract. Failure to comply with those federal requirements can result in federal-aid ineligibility notices and even the withdrawal of federal aid. One of Caltrans's objectives for developing an integrated DWR system is to eliminate costs incurred as a result of federal-ineligibility notices (Caltrans 2010). While some requirements like Disadvantaged Business Enterprise (DBE) requirements are managed during the bid letting, other requirements such as minimum wage rate are verified by conducting a brief interview of the construction workers on site. In addition, the DWR data is also required for office audits, material audits, and other reporting.

5.4.17 Public Information

The Freedom of Information Act (FOIA) provides the right to any person to access federal agency records except if those records are protected from public disclosure by exemptions or by special law enforcement record exclusions (U.S. Department of Justice 2011). Similar acts exists for state DOTs (see for example DelDOT (2014)). Under those acts, when DWR data or a portion of the data are requested by any person, the information should be provided to the person. The DWR data can become particularly useful to the public and law enforcement agencies in cases such as traffic incidents. Other entities like the city council and media can also request such information when required.

The DWR system can also be integrated with traveler's information websites for real-time updates on the road closure information. A study by Bourne et al. (2010) estimated that up to 80% of the planned lane closures are requested but are not actually closed. Those planned lane closures dates are identified during the preconstruction meeting and are uploaded in the traveler's information website such as http://www.511ia.org. Such "phantom" road closures will result in the road users' inconvenience. The reasons for "phantom" road closure may be because of early completion of a project or utility relocation delays, unfavorable weather to start the construction, resource management between multiple projects by the contractor working in the project, etc. The information published in the traveler's information is used by road users as well as media and can be misleading if not updated in real-time. A study showed that 32% road users are dissatisfied with work zone management (Bolling 2000). It essentially increases the road users' costs, comfort, and satisfaction level which are not accounted when contractors are prepared. Currently, the traveler's information system and the DWR systems are disintegrated, i.e. information is not passed from one system to another. The digital and, especially, web-based DWR system can be integrated with the traveler's information to provide real-time road closures and work zone information. Collecting this real-time information will require some additional efforts from the inspectors but if the systems are integrated, the additional effort would be minimal. Such information can, again, be obtained automatically using some of the equipment location, i.e. if some of the equipment to be used in the site is located in the construction site, the construction is in progress and hence the road or a lane is closed.

5.4.18 Feedback System for Improving Design and Specifications

One of the remarks noted during the construction is the various issues faced during the construction. One such issue may be the design and specification issues for various issues like differing site conditions (Figure 5.8). Those issues may occur more frequently in a specific set of items at specific locations. If such issues are noted in DWR systems in a structured format, the frequent design and specification issues may be identified. One application would be to improve the Context Sensitive Solutions (CSSs). CSSs include the design of transportation projects that fit the environment, preserves the scenic, aesthetic, historic, and environmental resources while maintaining the safety and mobility (IaDOT 2013). The need for a context sensitive solution may not be identified before the construction begins, but it can be identified as construction progresses. Such needs can then be noted down in the DWR system so that the need will be noted during the design phase when another construction project is initiated in the same location or nearby. UDOT, for example, has post-construction meetings where lessons learned on the construction projects are identified and feedback on design is provided by the contractors (Doehring 2014). Oregon DOT design groups such as bridge, roadway, and geo-hydro also reviews such information as change orders to improve their construction designs and specifications. If the design issues behind such change orders are noted in the DWR system, it can become a valuable feedback system to improve the existing design procedures.

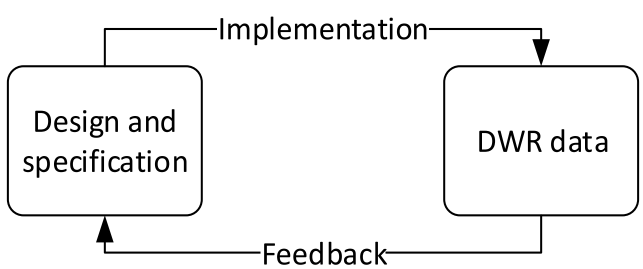


Figure 5.8 Design and specification improvement using DWR data

5.4.19 Text Analytics

Large amounts of remarks text data are collected in the DWR system that can be utilized for text analytics. An example can be to check the type of remarks often collected by field personnel and develop a GUI to collect structured data for the type of remarks that are collected frequently. It can also be used to generate a list of words for auto-completion when typing remarks. Another example can be to identify the frequent issues and causes of delays encountered during construction.

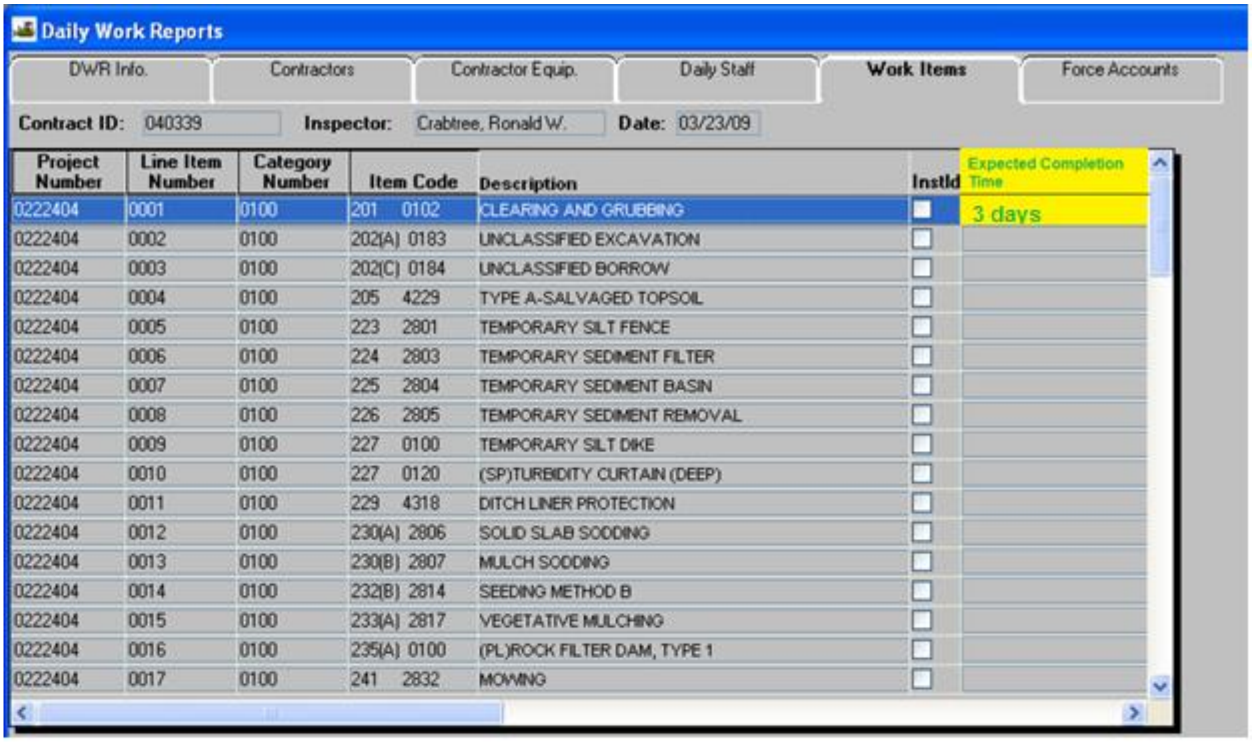
5.4.20 Predictive Analytics

With the concept of big data getting more popular in other fields, the concept is being introduced in the construction industry as well. The big data deals with the volume, velocity, and variety of the data (Sicular 2013). In the horizontal construction industry, the DWR data is probably the largest set of semi-structured data being collected in terms of volume. The system is developed to collect multiple data attributes every day from multiple projects running simultaneously across the state. Finally, the data set contains structured data attributes as well as semi-structured remarks, and unstructured image and document files that represent the variety.

The concept of big data is essentially related to predictive analytics based on clustering and classification systems that identify the patterns based on the historical data to predict the future scenarios. The most important part to analyzing the big data after its collection is the understanding of the right questions to ask or knowing the business case uses. Current practices in the construction industry show that the DWR data is used mostly for historical reporting.

If the predictive analytics is integrated into the DWR system, it will allow the decision makers as well as field personnel to plan accordingly. Some of the applications of the predictive analytics have already been pointed out in previous subsections. Those applications and more are presented together in this section.

One simple example of the application of the DWR data is the prediction of the duration to complete various project activities. When the estimated completion date of ongoing activities is known, inspectors can plan accordingly to be in the site when the work will be finished so that he or she can inspect and approve the work as soon as it is completed. This will be specifically useful when an inspector is handling multiple projects at once. It also becomes useful if the DOT (see for example South Carolina: Colvin (2008)) hires consulting staffs to inspect the projects. This way, the contractor will be able to fix any quality issues quickly before the equipment and the labor performing the work shifts its focus to another activity.


Daily Work Reports

DWR Info. | Contractors | Contractor Equip. | Daily Staff | Work Items | Force Accounts

Contract ID: 040339 Inspector: Crabtree, Ronald W. Date: 03/23/09

Project Number	Line Item Number	Category Number	Item Code	Description	Instld	Expected Completion Time
0222404	0001	0100	201 0102	CLEARING AND GRUBBING		3 days
0222404	0002	0100	202(A) 0183	UNCLASSIFIED EXCAVATION		
0222404	0003	0100	202(C) 0184	UNCLASSIFIED BORROW		
0222404	0004	0100	205 4229	TYPE A-SALVAGED TOPSOIL		
0222404	0005	0100	223 2801	TEMPORARY SILT FENCE		
0222404	0006	0100	224 2803	TEMPORARY SEDIMENT FILTER		
0222404	0007	0100	225 2804	TEMPORARY SEDIMENT BASIN		
0222404	0008	0100	226 2805	TEMPORARY SEDIMENT REMOVAL		
0222404	0009	0100	227 0100	TEMPORARY SILT DIKE		
0222404	0010	0100	227 0120	(SP)TURBIDITY CURTAIN (DEEP)		
0222404	0011	0100	229 4318	DITCH LINER PROTECTION		
0222404	0012	0100	230(A) 2806	SOLID SLAB SODDING		
0222404	0013	0100	230(B) 2807	MULCH SODDING		
0222404	0014	0100	232(B) 2814	SEEDING METHOD B		
0222404	0015	0100	233(A) 2817	VEGETATIVE MULCHING		
0222404	0016	0100	235(A) 0100	(PL)ROCK FILTER DAM, TYPE 1		
0222404	0017	0100	241 2832	MOWING		

Figure 5.9 Predictive time of completion of project activities

Similarly, the concept can be further used to predict the delays of the completion of the whole project based on the current performances and the weather issues. Oliveros & Fayek (2005), for example, developed a fuzzy logic-based method to determine the project delay based on the as-planned schedule and the as-built schedule to the data from the DWR system.

Another application would be to identify a list of controlling activities based on the activities that have been marked as controlling activities in previous projects. The activities thus identified can become a valuable piece of information for generating a predictive scheduling system by utilizing the activities to generate a logical connection between the project activities for the critical path scheduling method.

DWR data can be further utilized to analyze the trend of various aspects of the projects as presented in Table 5.7.

Table 5.7 Possible trend analyses based on DWR data

Factors	Trend (count, amount, percentage, etc.)					Additional trends
	Time	Location	Type (of factor under consideration)	Contract type	Contractor	
Claims and disputes	X	X	X	X	X	Resolution type/winner, dispute to litigation
Road closure performances (phantom road closures)	X	X	X	X	X	
Change orders	X	X	X	X	X	Change order approval rate
Cost performances	X	X	-	X	X	S-curve type planned versus actual, major causes
Schedule performances	X	X	-	X	X	S-curve type planned versus actual, major causes
Weather delays	X	X	X	X	X	
Significant conversation with contractors	-	-	-	-	-	Types
Labor compliances	X	X	X	X	X	

Taking an example of trend analyses of claims and disputes from the Table 5.7, following questions can be asked and answered based on DWR data:

- What is the trend of the number of disputes over the year?
- Which locations have fewer disputes?
- What type of disputes is more frequent (e.g. quantity dispute, specification and drawing interpretation, etc.)?
- What type of contracts usually has fewer disputes?
- Which contractor is usually associated with fewer disputes?
- How is the dispute resolved without having to go through litigations?

If the number of disputes is decreasing over time, it may be because of recent changes in the DOT policies. If there is an increase in the trend of disputes, the relevant factors can be identified to improve the current construction management process. For example, it may be possible that most of the disputes are related to a particular type of project conducted by a particular contractor. A similar analogy can be made about a change order trend. For example, the reasons for change orders, such as the addition of pay-items, differing site conditions, incentives, price adjustments, etc., can be analyzed against project types, location, etc. Those trends can then be used to improve future construction projects by predicting the possible types of errors, possible types of changes that may arise, possible cost underrun/overrun, etc. It can be further used by RCEs to approve the change orders, i.e. if similar change orders were frequent in the past, the change order is likely to be valid in the current project as well; if not, a more detailed analysis may be necessary to approve the change orders. If the change orders for similar pay-items, for same contractors, for given location, and type of project are analyzed, it may be possible to automate smaller change orders without the need for RCE intervention.

5.5 Visualization of Data

The importance of data visualization has been increasingly recognized in the construction industry. Visualization can also be considered one of the DWR applications. Most of the current analyses performed by the state DOTs are reported using tabular data that is very hard to decipher to make any conclusions based on that. The visualization techniques can be a solution for presenting complex data and information clearly.

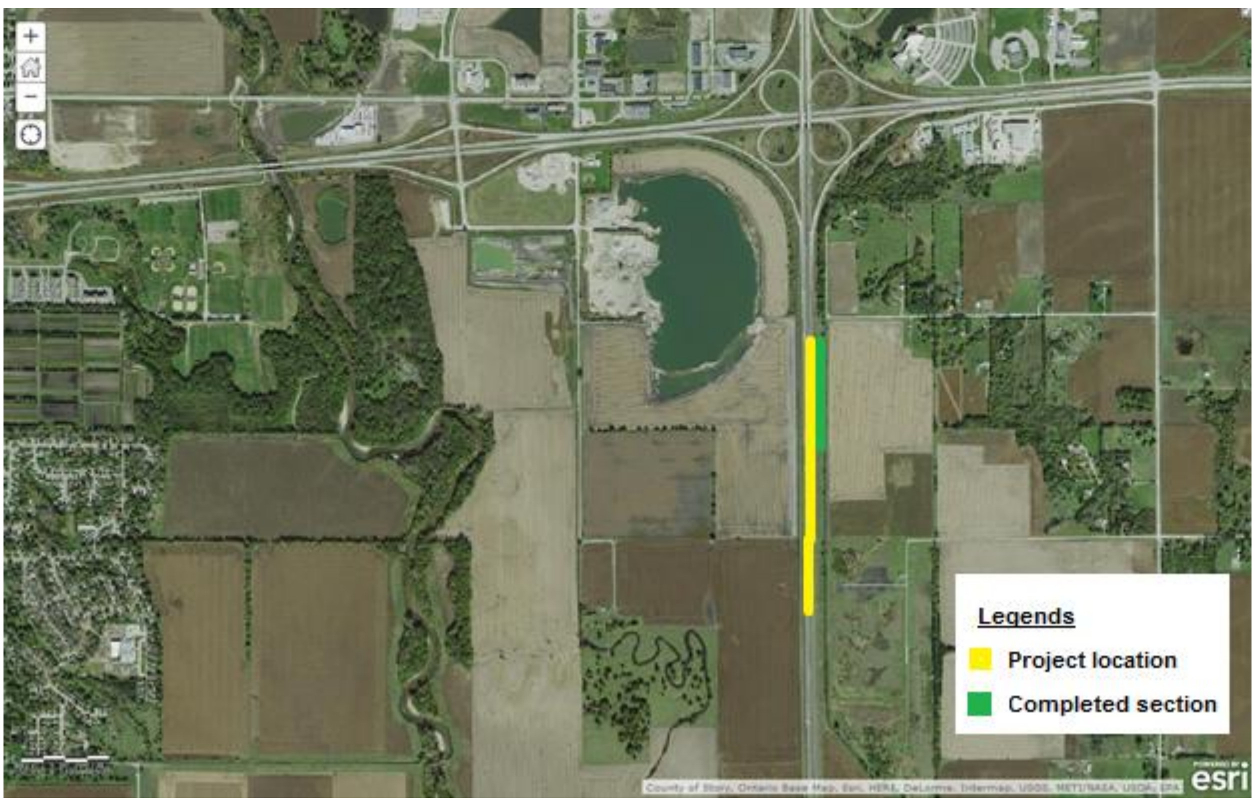


Figure 5.10 Visual Progress Monitoring (Adapted from ESRI (2014))

The visualization of construction progress of various projects as well as the progress of various activities of a particular construction project can be considered one of the simple DWR data visualizations. The construction progress project can be presented in GIS maps (Figure 5.10) for time-lapse project progress and as-planned versus as-built schedule diagram for the activity progress within a project. Even more useful visualization should consist of an interactive visualizer in which data can be analyzed in drill down fashion starting from overall status of the DOT projects to specific activity progress. For example, an initial screen can show project locations that project completion statistics by location. Clicking on a certain project can then show the itemized activity progress for that particular project and so forth. Such a unified visualized dashboard will allow decision makers to have a holistic overview of the ongoing and past projects to make decisions.

5.6 Human Factors

The DWR system is used primarily by Residential Construction Engineers (RCEs) and inspectors to record daily activities and any issues in a construction site. It is then used for approving contractor payments, generating various reports for upper management, and is also audited by accounting teams. Each of those teams that are directly using the DWR systems should be trained to make the best use of the system. More specifically, the RCEs and inspectors should be well-trained and motivated to record all the required data in the system. Data quality concern was one of the major issues identified in this study. At first, it was noted in the survey questionnaire. Later, the DWR database obtained from one of the state DOTs showed the same issue. Although, the DWR or Daily Work Report was supposed to be recorded every day, state DOTs seemingly have varying practices in data recording frequency. For example, one state DOT database showed that the data are recorded periodically at an interval of about a week. Rich (2006) also noted that the DWR date and work performance day may not correspond in current business practices. For example, the quantity may be recorded at a later date when the work quality is not satisfactory. In addition, the quantities may be adjusted when no work was performed. This will essentially result in misleading analyses such as production rate calculations.

To make better use of the data, the business practice of collecting data should be changed and data should be collected more frequently. Such a change in business practice needs the support from higher management teams. The business practice as well as the DWR systems should be updated periodically based on the feedback to improve it.

5.7 Other Technical Aspects

Some technical aspects to be considered while developing and using DWR systems include the development of intuitive User Interface (UI), the use of proper hardware, and regular updates. Some of the users stated that the current DWR systems they are using have outdated UI. More intuitive and simple UI means fewer training requirements. One state DOT representative mentioned the difficulty in recording change orders in their system. When systems are difficult to use, either it requires more training to be used or there is a good possibility of the data not being collected properly. It is worth noting that one of the key factors behind Apple, Inc.'s success is its focus on intuitive and easy to use UI (Bajarin 2012). Some of the technical aspects that should be considered are (Caltrans 2010):

- Search function to search contracts, remarks, specific DWR, etc. including instant search (type and go filter),
- Data entry validation, such as a possibly erroneous data input warning (e.g. entry of future date, redundant entry of same labor data by two inspectors),
- Scalable to store more data more frequently by more users,
- Digital signature.

The survey conducted for this study identified that search functionality is missing in the ASM and is a preferred feature by the inspectors to find a relevant diary and corresponding project. In current systems, users have to go through each day's DWR data manually to find relevant data.

Other useful functionalities may be the built-in quantity calculator, attention flag to highlight issues, automatic entry of default values (such as current date), SQL query system to create new reports from stored data, and the use of existing accounts of employees to log in to the system.

As mentioned earlier, the systems also need to be updated regularly based on the changing needs of the users. The ASM, for example, is updated every six months addressing various feedback and issues collected over time.

Finally, as mentioned in the " Advanced Data Collection Systems" section, the computing world is moving to web-based and cloud technologies. Web-based technologies are often considered the way to go for the future. It only makes sense to move to web-based technology for the DWR system. This is recognized by the AASHTO, and they have moved forward to develop a web-based DWR system.

5.8 Possible Challenges Expected to be Solved or Eased by Implementing the Ideal DWR Framework

The framework presented above is expected to ease the challenges identified in the study. Table 5.8 below presents the components and possible challenges that are expected to be solved or eased by the component, along with a short description of the components. Figure 5.11, Figure 5.12, and Figure 5.13 compare the current DWR systems with ideal DWR systems.

Table 5.8 Components of proposed DWR framework and its contributions

Component	Description of the component	Need of improvement	Possible challenges that can be overcome
Data model	Focus on systematic data attributes rather than linguistic data. In addition to data attributes, proper relationships between data attributes are also necessary (for example, activity level resources data versus day level resources data).	Medium	Quality of data, lack of proper data attributes, and resources limitations.
Integration with existing systems	DWR system should be integrated with other systems such as accounting systems, project planning systems, and cost estimation systems to reduce duplication of efforts and ease various analyses.	Medium	Quality of data, resources limitations, duplication of efforts, and current business practices.
Visualization	Visualization of data to provide required data intuitively to the decision makers. Can use drill down approach to present detailed data from top to the bottom. Data can also be visualized for public to understand current project progresses as well as to provide real-time work zone information.	High	Resources limitations, Technical limitations, and current business practices.
Advanced data collection systems	Similar to the concept of connected vehicles in traffic engineering, construction equipment and other connected data collection systems such as RFID, bar code, equipment sensors, web-based weather data, GPS, LiDAR, and mobile devices can be used to ease data collection efforts.	High	Quality of data, resources limitations, and duplication of efforts.
Automation of DWR analysis and reporting	Currently not many analyses are automated and there are no apparent efforts toward the use of predictive analytics with DWR data. Predictive analytics will require the use of data mining techniques. Automation will require better data models of DWR data followed by development of algorithms for those analyses.	High	Resource limitations.
Human factors	DWR system users need to be trained properly to collect consistent and timely data in the system. Data should be collected frequently (with due consideration of available resources) for which managerial support is required.	Medium	Quality of data and current business practices.
Other technical aspects	Use of intuitive user interface, proper hardware, regular update of the system to resolve any issues encountered, web-based system development, and application development for tablets.	Medium	Quality of data, resources limitations, and duplication of efforts.

The reduced data collection and analyses efforts will enable decision makers to improve their decision making process. Real time availability of the reports will also enable better control over the project costs and schedule as potential issues can be identified before it impacts the project. This in turn can reduce the road users' costs as more benefits can be obtained from less costs. The real time exchange of data will also improve the relationship between project stakeholders including state DOTs, contractors, and road users.

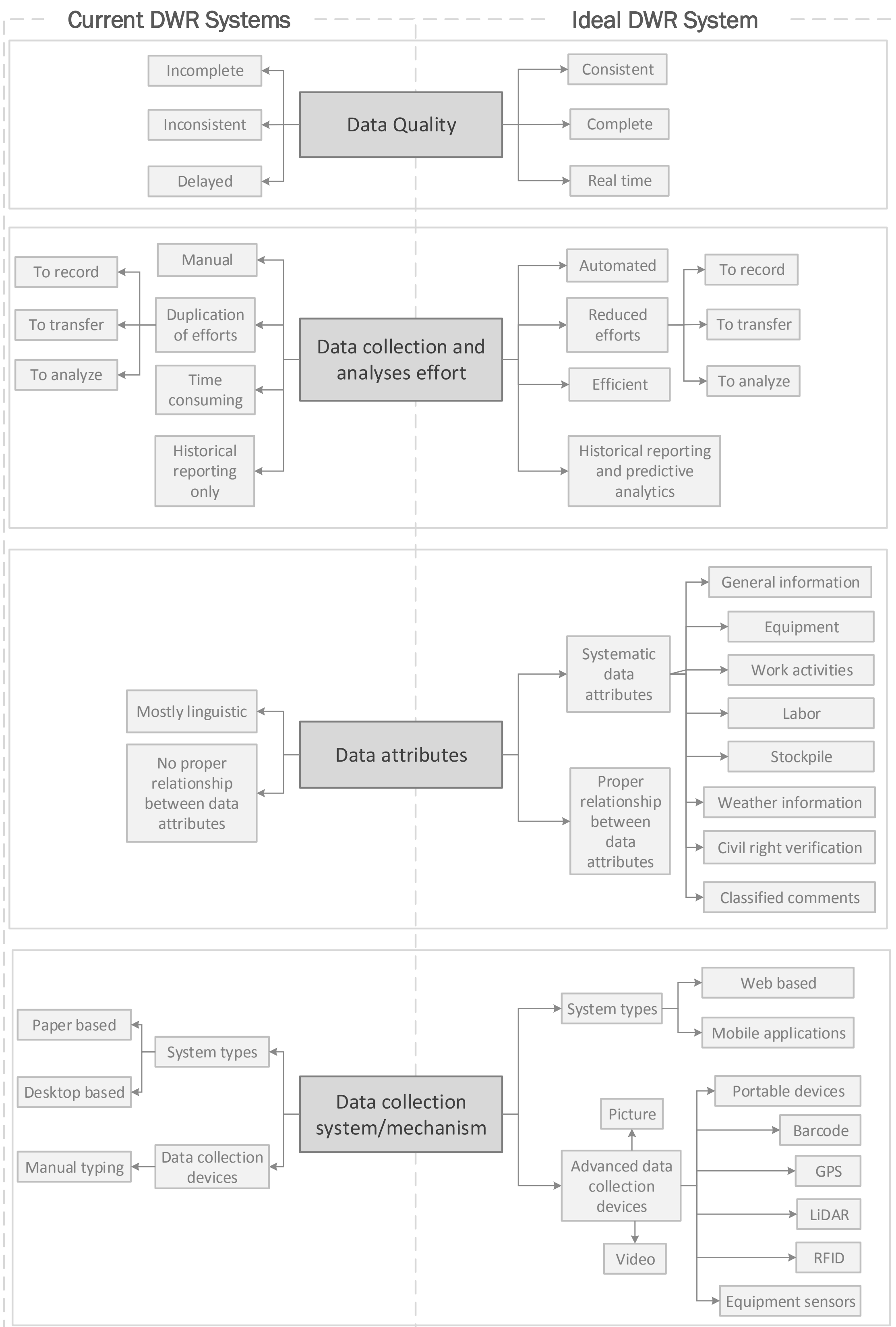


Figure 5.11 Current DWR systems versus Ideal DWR system in terms of data collection

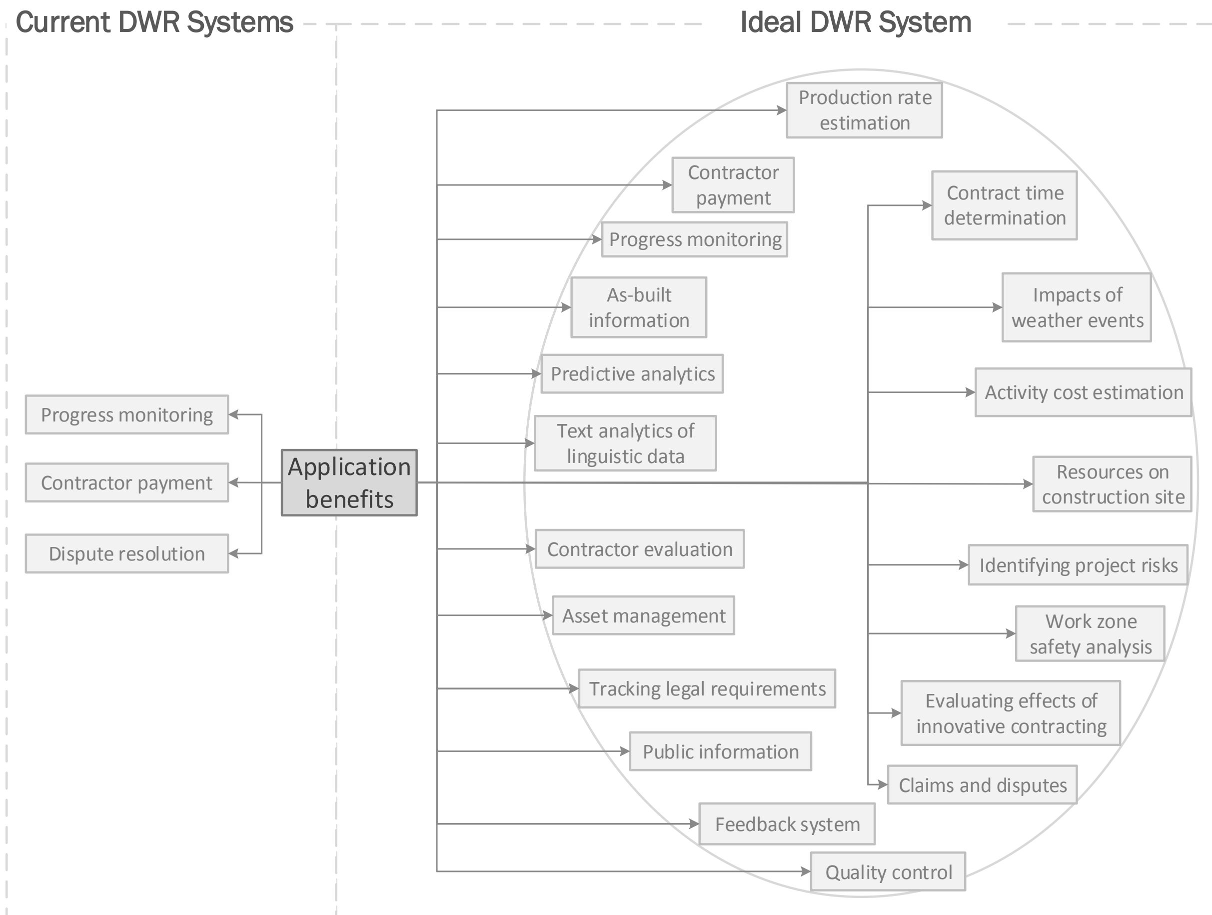


Figure 5.12 Current DWR systems versus Ideal DWR system in terms of various application benefits

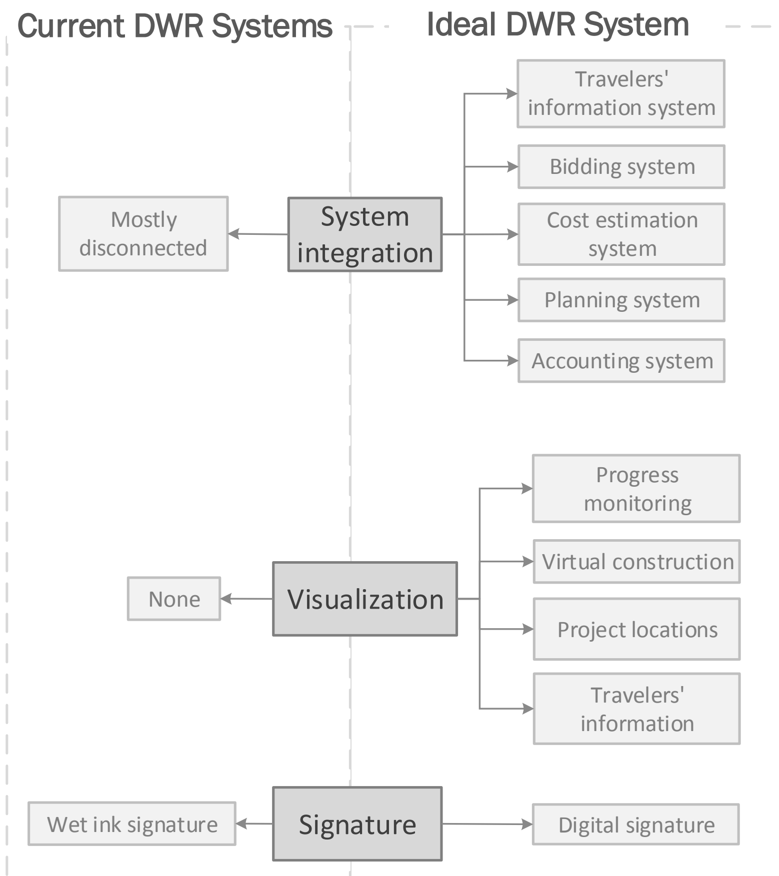


Figure 5.13 Current DWR systems versus Ideal DWR system in terms of system integration, visualization, and signature

5.9 Validation of Proposed Framework

The framework developed in this study was validated by seven DWR experts from the U.S. These seven DWR experts are from Michigan, Oregon, Delaware, California, and Pennsylvania. The validation was performed via a questionnaire survey and it focused on soliciting expert opinions on an overall advancement provided by the framework over existing DWR systems. The version of the framework sent to the experts along with the questionnaire survey is included in Appendix E and F. In the questionnaire, the experts were asked to rate various aspects of the framework on the scale of 1 to 10 – 1 being “poor” or “strongly disagree” and 10 being “excellent” or “strongly agree.” The quantitative analysis results of the responses are provided below followed by qualitative analyses and conclusions.

The DWR experts provided overall positive responses along with some constructive feedback. The experts commented that the framework is promising to improve existing DWR systems. This is also indicated by the average rating of 8.0 out of 10 (Table 5.9). They supported the concept of an integrated and web based DWR system provided in the framework.

Table 5.9 Average ratings of the proposed DWR framework

S.N.	Question	Average Rating
1	This framework proposes some useful advancement over current DWR systems.	7.3
2	This framework can aid in tackling current challenges (listed below) of getting benefits from current DWR systems:	
2.1	Lack of proper data attributes	6.4
2.2	Resources limitation	6.3
2.3	Duplication of efforts	7.2
2.4	Technical limitations	6.8
2.5	Current business practices	6.3
3	Current DWR systems can adapt some parts of the framework to improve their existing system.	8.0
4	The framework can be adapted to develop a DWR system if a state DOT does not have one.	8.3
5	The framework is comprehensive in terms of its scope.	8.5
6	The framework is easy to comprehend.	7.7

The ratings also show that the framework proposes some useful advancement over current DWR systems (7.3 out of 10). The framework is of high level and is comprehensive in terms of its scope for that level (8.5 out of 10). It is also easy to comprehend by DWR experts (7.7 out of 10). Finally, it is fairly good to overcome existing challenges that were identified in this study as indicated by the ratings for items 2.1 through 2.5 (rating of over 6 out of 10).

Further qualitative analysis of the comments provided by the experts revealed additional insights about the framework. For example, although the framework is very promising, state DOTs would still need to do additional work to adapt the framework and implement it in their organizations. Similarly, the DWR data should be stored in a location that is accessible to relevant personnel within the agency who can analyze the data for the benefits of their teams. At the same time, proper security measures should be implemented in the system so that only authorized personnel would be able to view and make changes to the stored data. Similarly, the users should have a personalized user interface based on their role in the system. A version control system was also recommended. A version control allows the system to track changes made over time which can increase the credibility of the electronic DWR data. Such system might provide the electronic DWR data same weight as paper based DWR data in case of legal issues.

Additional improvements for the framework included the implementation of offline capability in mobile based DWR systems and a capability to provide various reporting systems to meet different needs across the agency. Those reporting capabilities identified by the experts are:

- Item level quantity tracking,
- Item level funding and expenditure tracking,
- Justifying contractors' billings based on DWR data,
- Item-quantity overrun/underrun,
- Change orders by project and location,
- Predicting the effect of quantity overrun/underrun and change orders to the project funding.

6 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations derived from the findings of the study. It also presents a brief description of the proposed framework along with recommendations for implementation. Finally, the expected contributions of the framework are presented.

Inspectors and Resident Construction Engineers are responsible for the collection of Daily Work Report (DWR) data in the construction site and can use the data for multiple applications. For example, the data can be used to monitor construction progress, make contractors' payments, determine resources employed in a construction site, quantify the effect of weather on contract time, and resolve claims and disputes.

The DWR data were traditionally recorded in paper-based DWR systems. But the paper-based systems are not convenient and efficient. Paper-based DWR systems result in a duplication of efforts, errors while transferring data, and can be more expensive in terms of costs and space required. Additionally, analyzing paper-based DWR data is much more challenging and takes a lot of manual effort, which adds challenges for resolving claims and disputes. As such, electronic DWR systems were studied and developed over time, taking care of many limitations of the paper-based DWR systems. Such electronic systems have resulted in cost savings of millions of dollars for state DOTs because of reduced duplication of efforts and timely decision makings based on automated data collection and analyses.

The review of existing DWR systems used by state DOTs showed that the systems developed by combined efforts of multiple state DOTs generally had more data attribute collection capabilities compared to State Specific Systems (SSSs) to collect DWR data. The collection of detailed data attributes also opens the possibility for more detailed data analyses that can be used for data-driven decisions throughout the lifecycle of current and future projects.

Although electronic systems were introduced to state DOTs as early as the late 1960s, three state DOTs are still using paper-based DWR systems. At the same time, many state DOTs (23) reported that they are using paper-based DWR systems along with electronic DWR systems. Departmental policies such as "wet ink signature" requirements and a lack of proper devices for on-site use have created challenges to go completely paperless. Only fourteen states have reported to be using electronic DWR systems only. Two thirds of the respondents who are currently not using an electronic DWR system are planning to use an electronic DWR system in near future.

The survey noted that three electronic DWR systems are being developed by the combined effort of multiple state DOTs. Those systems are AASHTOWare SiteManager (ASM), Maintaining Assets for Transportation System (MATS), and AASHTOWare FieldManager (AFM). Among those, ASM was the most popular system in terms of the number of state DOTs using it (20). Another eight DWR systems found in the study were developed by individual state DOTs.

Although a lot of time is spent in collecting DWR data, there are still multiple challenges to fully utilize the data being collected. Many challenges were applicable even to state DOTs that have already implemented electronic DWR systems. Those challenges were classified and presented under six categories—quality of data, resource limitations, duplication of efforts, lack of proper data attributes, technical limitations, and current business practices—and were used to develop an ideal framework for an advanced DWR system. Comments and suggestions received for improving current DWR systems were also presented for each system.

The first nationwide questionnaire survey noted there were only three application benefits of DWR systems that were obtained by more than 80% of the respondents. Those three application benefits were progress monitoring, contractor payment, and dispute resolution. Another eight application benefits were obtained by less than three-fourths of the respondents. Those benefits were as-built information, activity cost estimation, production rate estimation, identification of project risks, contractor evaluation, contract time determination, safety analysis, and evaluation of the effects of innovative contracting methods. This shows a huge gap between the possible application benefits of the DWR data and the actual application benefits obtained by the state DOTs. A second national survey questionnaire was used to test researchers' hypothesis that the lack of automation for various applications of DWR data is the main reason that state DOTs are not obtaining those benefits. Overall, there was a consistency between the level of automation (rating) and percentage of respondents who obtained the benefit. As such, lack of automation may be the reason behind state DOTs not obtaining those benefits. Improving the level of automation is likely to improve the level of benefits obtained by the state DOTs.

Finally current applications of DWR systems are mostly limited to the reporting of historical information rather than use of predictive analytics. In this era of big data, many industries are utilizing the predictive analytics with their big data using advanced data mining techniques. But, no such efforts have been noticed in the DWR systems. The current systems also lack visualization tools, such as interactive dashboards, that can be used for exploratory data mining. The actionable knowledge generated from visualization and predictive analytics can be used for more effective decision making, such as "realistic" schedule generation, more reasonable claim payment, early identification of project risks based on historical data, etc. Thus a proper framework can be a valuable tool for successful completion of construction projects.

An ideal framework was developed for an advanced DWR system based on reviews of existing literature related to the application of DWR data, reviews of existing DWR systems, and findings of survey questionnaires. The proposed framework consists of seven components: data model, interoperability, data visualization, advanced data collection system, automation of data analysis and reporting, consideration of human factors, and other technical aspects. The framework was validated by seven DWR experts in the U.S.

The framework was developed to tackle the challenges identified from previous studies. Some of the key points of the framework that distinguishes it from the existing systems are:

- Complete, consistent, and real time data availability,
- Automation, reduced efforts, and efficient data collection and analyses,

- Historical reporting as well as predictive analytics,
- Systematic data attributes along with proper relationship required for various analyses,
- Advanced data collection system for automation of data collection,
- Web-based and mobile-based systems,
- Integrated systems,
- Visualization component,
- Digital signature,
- Increased applications of the DWR data.

The framework proposed 20 different application benefits and proposed automation for selected applications. The proposed framework is expected to be useful in developing a new DWR system as well as improving existing DWR systems. The implementation of the systems is expected to improve the overall level of benefits obtained by the state DOTs based on the DWR data. Additionally, its implementation is expected to:

- Improve the decision making process for future projects,
- Improve the project costs and schedule control,
- Reduce road users' costs by increasing the benefits of investments, and
- Improve the relationship between project stakeholders.

It should be noted that, some aspects of the framework may not be applied at the current time. As such the framework is called an "ideal" framework.

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APPENDIX A. IOWA DOT RCES' INTERVIEW GUIDELINE

Interview Guideline for Daily Work Report (DWR) Collection and Utilization by Iowa DOT District Offices

Iowa State University is conducting a Mid-America Transportation Center funded research project to develop a framework for an advanced Daily Work Report system. The main goal of this interview is to study current best practices for collecting, analyzing, and utilizing the Daily Work Report (DWR). The results of the interview will be used to prepare a better questionnaire for the national level survey on the same topic.

The confidentiality of this interview will be maintained. The identity of the person who provided the information will remain anonymous. The data obtained during this interview will not be linked in any way to the participant's name.

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A. Data Collection

1. How do you collect the DWR data? Who collects the data, who inputs it in the computer system, who uses the data afterward? Do you provide the DWR data to the district or state DOT office? Do you know how they use the DWR data?
2. What application programs are used for collecting, storing, and retrieving DRW data?
3. Do you know of any other application programs that other state DOTs or other agencies use?
4. What DWR data are collected in the field? Do you collect how much work is done for a particular task (in terms of percentage)? Which activities have been started and which activities have not?
5. Are there any data that you think should be collected and are useful but not collected? If yes, what are those data and what are their usages?
6. How much time (% of total work hour) does the site engineer spend on collecting the Daily Work Report?

B. Data Usage

7. What are the current usages of the data collected? In other words, why DWR is used.
8. Do you analyze project specific data analysis or office wide data analysis?
9. Do you use any visualization tool for analyzing DWR data? If yes, what tools do you use and how do you use it? If not, do you think it will be useful? Do you know any such tool? What kind of visualization tools would be useful?
10. What additional decisions can be made from the data?
11. On the scale of 1 to 5 (1 being least and 5 being highest), how well are the DWR data being used for data-driven decision making?

C. Others

12. Do you know any differences between the DWR system of your district or Iowa and other state DOTs?
13. What are the challenges for collecting and utilizing the DWR data?
14. ---If any (Would you email me the template you use to collect the field data or web link to the file?)
15. Any additional comments regarding the Daily Work Report data collection?

APPENDIX B. FIRST NATIONAL QUESTIONNAIRE SURVEY

Current Practices of Using Daily Work Report System

Iowa State University is conducting a Mid-America Transportation Center funded research project to develop a framework for an advanced Daily Work Report system. The main goal of the survey is to study the current best practices for collecting, analyzing, and utilizing the Daily Work Report (DWR). The DWR refers to the various data collected in the construction site, including but not limited to the quantities of works performed, quality inspection results, material usages, labor, and equipment usage.

We would like you to participate in this survey and provide us with your valuable opinions about DWR. Any comments about the questionnaire will be used to update the questionnaire for a nationwide survey. The time required to complete this form is approximately **7 minutes**. Please return the completed survey by **March 31, 2014**.

If you have any questions, please feel free to contact me via e-mail or phone. The confidentiality of this questionnaire will be maintained. The identity of the person who provided the information will remain anonymous. The data obtained during this interview will not be linked in any way to the participant's name. You can return the completed survey via e-mail or mail to the following address:

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E-mail: djeong@iastate.edu
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Phone: 702-518-1175

A. General Information

1. Please provide your contact information.

Agency: ____

State: ____

Respondent: ____

Position: ____

Phone number: ____

E-mail: ____

Date: ____

B. Current DWR Data Collection Practices

2. How does your agency collect, store and maintain the DWR data? Select all that applies.

[ ] Paper-based collection

[ ] AASHTOWare Field Manager and Field Book

[ ] AASHTOWare Site Manager

[ ] Autodesk Constructware

[ ] Others (mention)

____

2.1 If a software program is used for collecting the DWR data, does your agency maintain statewide DWR data in a central database that can be readily accessed for various analysis?

[ ] Yes [ ] No

2.2 If a software program is not used, does your agency plan to use electronic data collection and storage method in near future?

[ ] Yes [ ] No

3. Are there any policies, procedures, or manuals for collecting the DWR data or using the DWR software program in your agency?

[ ] Yes [ ] No

4. Which of the following benefits are obtained by analyzing DWR data in your agency? Please rate the importance of DWR data for those analyses. Please add any additional benefits of DWR data.

   (Rating: 1 – not important and 5 – very important)

Benefits of DWR data analysis	**Yes/No**	**1**	**2**	**3**	**4**	**5**
Dispute resolution						
Pay application approval						
Contractor evaluation						
Progress monitoring						
As-built information (cost, schedule, etc.)						
Production rate estimation						
Activity cost estimation						
Contract time determination for future projects						
Safety analysis						
Evaluating the effect of the innovative contract methods in project duration, cost, etc.						
Identifying project risks (e.g. causes of cost and schedule overrun)						

5. Please indicate whether the following DWR data are recorded in the main DWR application (Field Manager, Site Manager, etc.), other forms, or both. Please rate the importance of those data to get the benefits mentioned in question #4. Please add any additional field data that are important to obtain those benefits.

   (Rating: 1 – not important and 5 – very important)

Data	**Main Application**	**Other Forms**	**1**	**2**	**3**	**4**	**5**
Site conditions (location, weather, etc.)							
Pay-item-wise quantities of work performed each day							
Equipment usage details for each day							
Equipment usage details for each pay-item activity							
Crew details for each day							
Crew details for each pay-item activities							
Duration of each pay-item activity							
Causes of Delays							
Contractor’s progress schedule and reports							
Contractor’s quality assurance tests							
Agency’s quality assurance tests							
Non-compliance with contract terms							
Significant conversation with contractors							
Payroll review							
Traffic control reports							
Safety and incident reports							
Material delivery tickets							
Material certificates							

C. Additional Information

6. What are the challenges in your agency for the better utilization of the DWR data?

____

____

____

7. Any comments about the survey questionnaire?

8. Can we contact you later for further analysis?

[ ] Yes [ ] No

APPENDIX C. SECOND NATIONAL QUESTIONNAIRE SURVEY

Daily Work Report (DWR) Questionnaire Survey – Phase II

We would like to thank you for participating in the first survey questionnaire on the Daily Work Report (DWR). The DWR is also known as Inspectors Daily Report (IDR), Daily Report, Project Site Activity (PSA), etc. Your input in the phase I questionnaire was valuable for the study and for preparing this questionnaire. This is the **second and final questionnaire** for preparing a framework to advance the DWR system. **In this questionnaire, we would like to learn potential application areas and users of the DWR data in your agency, and possible case studies**. Efforts have been made to keep the questionnaire as short as possible. There are 5 questions in this questionnaire excluding the contact information.

We would like you to participate in this phase II survey and provide us with your valuable opinions. The time required to complete this form is approximately less than **12 minutes**. Please complete the survey by **August 25, 2014**. Except for the contact information, **you may skip some questions or sub-questions if you don't have clear answers**. The results of the questionnaire survey will be used for developing a framework for DWR that can be used to generate more actionable knowledge from DWR data. **A DWR framework developed from the study is expected to aid in making data-driven decisions throughout the highway project lifecycle**.

If you have any questions, please feel free to contact me via e-mail or phone. Your identity will remain confidential. The data obtained from this survey will not be linked in any way to the participant's identity.

Sincerely,

H. David Jeong
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Note: Except for the contact information, you may skip some questions or its sub-questions if you don't have clear answers.

A. Contact Information

1. Please provide your contact information.

State: ____

Respondent: ____

E-mail: ____

B. Potential Applications and Users of DWR Data

2. In the previous survey, you mentioned that DWR data is used for one or more of the following analyses. Please indicate the level of automation of those analyses (1 – requires a lot of manual work, 5 – fully automated) if you are using a digital DWR system. Also, for each item below, please explain how DWR data is used or can be used. For example, the total quantity of work is calculated (manually or automatically) to pay the contractor (or approve their request for payment).

Analysis	**Level of automation (1 – 5) / Not applicable / Don't know**	**Comments**
Dispute resolution		
Contractor evaluation		
Progress monitoring		
As-built information (cost, schedule, etc.)		
Production rate estimation of pay item		
Activity cost estimation		
Contract time determination for future projects		
Safety analysis		
Evaluating the effect of the innovative contract methods in project duration, cost, etc.		
Identifying project risks (e.g. causes of cost and schedule overrun)		
Design and specification issues		
Others 1 ______________		
Others 2 ______________		
Others 3 ______________		

3. Please answer this question **based on your experience and perception**. Assume that resource data such as material, labor and equipment is collected **at each pay item** level in the DWR system. Please indicate if the following team can benefit from the DWR data. Also,

indicate if those teams have already used the existing DWR data. Please provide some details on how they can use the DWR data (e.g. methodology, decisions) and any additional DWR data that can be useful for those teams.

Department / division / team	**Possibly benefit (Yes / No / Don't know)**	**Used (Yes / No / Don't know)**	**Comments on use case**	**Additional useful DWR data for the team**
Cost estimation team				
Scheduling team				
Accounting team				
Auditing team				
Design team				
Planning team				
Traffic safety team				
Asset management team				
Other 1 __________				
Other 2 __________				
Other 3 __________				

C. Additional Features of Digital DWR System

4. Please rate the usefulness of the following features that can be added in a digital DWR system. (Rating scale: 1 - not at all useful and 5 - very useful)

Feature	**Rating (1 - 5)**
Estimated time/duration of completion of current activity calculated and presented by the DWR system to the field personnel	
Automatic weather data collection from web sources for the project location	
Radio Frequency ID (RFID) for data entry	
Bar code for data entry	
Others 1 ___________	
Others 2 ___________	
Others 3 ___________	

D. Level of Details in DWR Data

5. Most highway agencies collect labor and equipment use data per day, but not broken down into each pay item level. In your opinion, how much additional amount of efforts are expected to increase if you collect daily labor and equipment use data at each pay item level? For this study,

Pay-item level detail for	Extra efforts in terms of % of extra time (compared to day level detail)
All pay-items	
Major pay-items	

(Note: assume that major pay-items are top 20% pay-items that correspond to 80% of the costs (80-20 rule or the Pareto principle).

6. Can we contact you later for further analyses?

   [ ] Yes [ ] No

APPENDIX D. CONTRACTORS' PHONE INTERVIEW

Interview Guideline for Daily Work Report (DWR) Collection and Utilization by Construction Companies

Iowa State University is conducting a Mid-America Transportation Center funded research project to develop a framework for an advanced Daily Work Report system. The main goal of the survey is to study the current best practices for collecting, analyzing, and utilizing the Daily Work Report (DWR).

The confidentiality of this interview will be maintained. The identity of the person who provided the information will remain anonymous. The data obtained during this interview will not be linked in any way to the participant's or company's name.

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A. Data Collection

1. How much time (% of total work hour) does the site engineer spend on collecting the Daily Work Report?
2. What application programs are used for collecting, storing, and retrieving DRW data?
3. What DWR data are collected in the field?
4. Are there any data that you think should be collected and are useful but not collected? If yes, what are those data and what are their usages?

B. Data Usage

5. What are the current usages of the data collected? In other words, why is DWR data collected?
6. Do you analyze project-specific data analysis or company wide data analysis?
7. What additional decisions can be made from the data?
8. On the scale of 1 to 5 (1 being least and 5 being highest), how well are the DWR data being used?

C. Others

9. What are the challenges for collecting and utilizing the DWR data?
10. Any additional comments regarding the Daily Work Report data collection?
11. If any, would you e-mail me the template you use to collect the field data?

APPENDIX E. PROPOSED DWR FRAMEWORK FOR VALIDATION

Proposed Framework for Ideal DWR System

The proposed framework for an ideal DWR system is developed based on extensive literature review, two nationwide surveys, interviews of Iowa DOT Residential Engineers, and review of existing DWR systems. The study found that many state DOTs are using electronic DWR systems without paper based DWR systems while many other state DOTs are using electronic DWR systems along with paper based DWR systems. Also, some state DOTs are still relying completely on paper based DWR systems. The electronic and paper based DWR systems identified in this study have varying level of functionalities.

The survey results showed that while many DWR data attributes are considered to be very valuable for various application benefits, many state DOTs do not fully take advantages of the collected data. For example, many state DOTs have limited the use of DWR data for progress monitoring, contractor payment, and dispute application while more than a dozen applications were identified in this study (Figure E.3). This might be because of various reasons such as lack of proper data attributes and lack of proper methodologies to automate those application analyses. Those various challenges faced by state DOTs for better collection and utilization of the DWR data are presented in Table E.1 along with possible solutions for improvement.

An ideal framework is proposed and presented in Figure E.1 by considering the challenges and possible solutions identified in Table E.1. Seven components of this ideal framework and possible challenges it is expected to solve or ease are presented in Table E.2. The comparison of the ideal framework with existing systems from various aspects are presented in Figure E.2, Figure E.3, and Figure E.4. As noted earlier, current DWR systems have varying level of functionality and as such the comparison may not necessarily be relevant to a particular DWR system. Also, it may be noted than not all aspects of the proposed ideal framework can be implemented soon (and hence called an "ideal" framework). However, the implementation of a part, if not all, of the ideal framework is still expected to improve the current practices and overcome challenges. The proposed framework is expected to be useful to update existing DWR systems as well as to develop a new DWR system. Overall, the implementation of the framework is expected to:

- Improve the decision making process for future projects,
- Improve the project costs and schedule control,
- Reduce road users' costs by increasing the benefits of investments, and
- Improve the relationship between project stakeholders.

Table E.1 Challenges of getting benefits from DWR data

Challenge	Description of the challenges	Possible solutions
Quality of data	-Varying level and quality of data provided by field personnel. -Staff turnover has added more challenge. -Inconsistency in the frequency of data collection	-Training, intuitive user interface to ease detailed data collection. -Update business practices if resources are available.
Lack of proper data attributes	-Some DWR systems have fairly comprehensive data attributes while others do not. -Many data are collected in linguistic format which cannot be analyzed easily.	-Identify more data attributes using text analytics of the linguistic data. -Develop a DWR system with capability to collect those data attributes.
Resource limitations	-DOT resources have shrunken in past. -Not enough people who are knowledgeable with technologies are entering the construction industry resulting in a challenging environment to implement technological innovations. -Not all field personnel may be comfortable with using computers.	-Introduce more efficient data collection methodologies. -Develop intuitive user interface. -Automation of various analyses and benefits.
Duplication of efforts	-State DOTs have policies such as "wet ink/signature requirements" which makes it necessary to use paper based systems in addition to electronic systems. -Lack of integration has resulted in collection of various data in disintegrated systems. As a result, analyzing those data requires extra effort.	-Develop integrated systems and automated data collection devices such as RFID, bar code, LiDAR, and GPS. -Update policies to enable use of newer technologies.
Technical limitations	Complexity when analyzing data from multiple disintegrated databases. -Lack of powerful and portable devices for data collection in field.	-Get newer devices and portable devices like tablets, lightweight laptops to ease data collection in electronic format directly in the field. -Develop web-based systems to ease the system maintenance.
Current business practices	-Lack of understanding of detailed data being collected in field.	-Communicating the detailed data being collected. -Brainstorming of the possible applications for other teams within an agency.

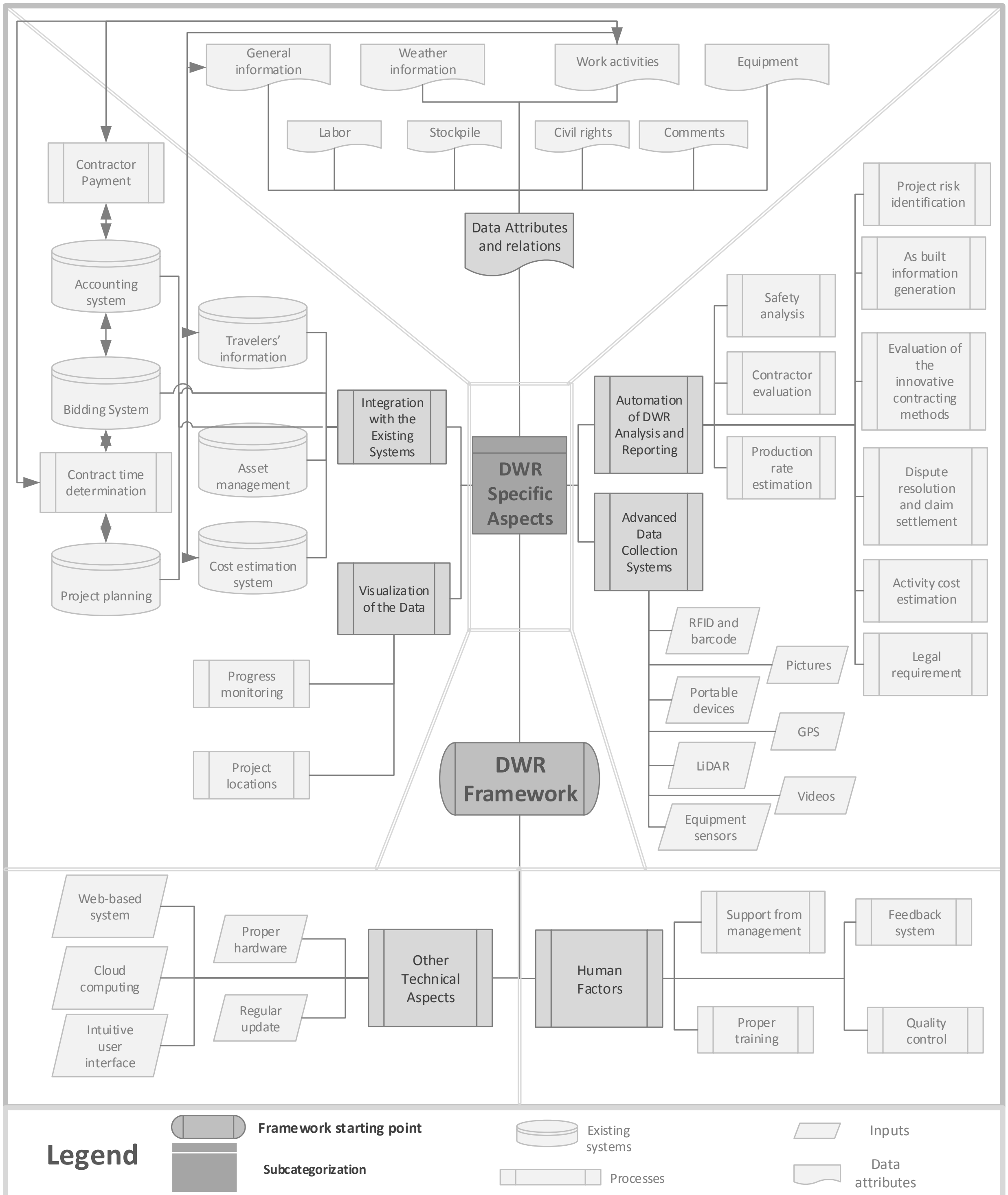

Figure E.1 Proposed advanced framework for an ideal DWR system

Table E.2 Components of proposed DWR framework and its contribution

Component	Description of the component	Possible challenges expected to be solved or eased
Data model	Focus on systematic data attributes rather than linguistic data. In addition to data attributes, proper relationship between data attributes are also necessary (for example activity level resources data versus day level resources data). A minimal data model is presented in Figure E.5.	Quality of data, lack of proper data attributes, and resources limitations.
Integration with existing systems	DWR system should be integrated with other systems such as accounting systems, project planning systems, and cost estimation systems to reduce duplication of efforts and ease various analyses.	Quality of data, resources limitations, duplication of efforts, and current business practices.
Visualization	Visualization of data to provide required data intuitively to the decision makers. Can use drill down approach to present detailed data from top to the bottom. Data can also be visualized for public to understand current project progresses as well as to provide real-time work zone information.	Resources limitations, Technical limitations, and current business practices.
Advanced data collection systems	Similar to the concept of connected vehicles in traffic engineering, construction equipment and other connected data collection systems such as RFID, bar code, equipment sensors, web-based weather data, GPS, LiDAR, and mobile devices can be used to ease data collection efforts.	Quality of data, resources limitations, and duplication of efforts.
Automation of DWR analysis and reporting	Currently not many analyses are automated and there are no apparent efforts towards the use of predictive analytics with DWR data. Predictive analytics will require the use of data mining techniques. Automation will require better data models of DWR data followed by development of algorithms for those analyses.	Resource limitations.
Human factors	DWR system users need to be trained properly to collect consistent and timely data in the system. Data should be collected frequently (with due consideration of available resources) for which managerial support is required.	Quality of data and current business practices.
Other technical aspects	Use of intuitive user interface, proper hardware, regular update of the system to resolve any issues encountered, web based system development, and application development for tablets.	Quality of data, resources limitations, and duplication of efforts.

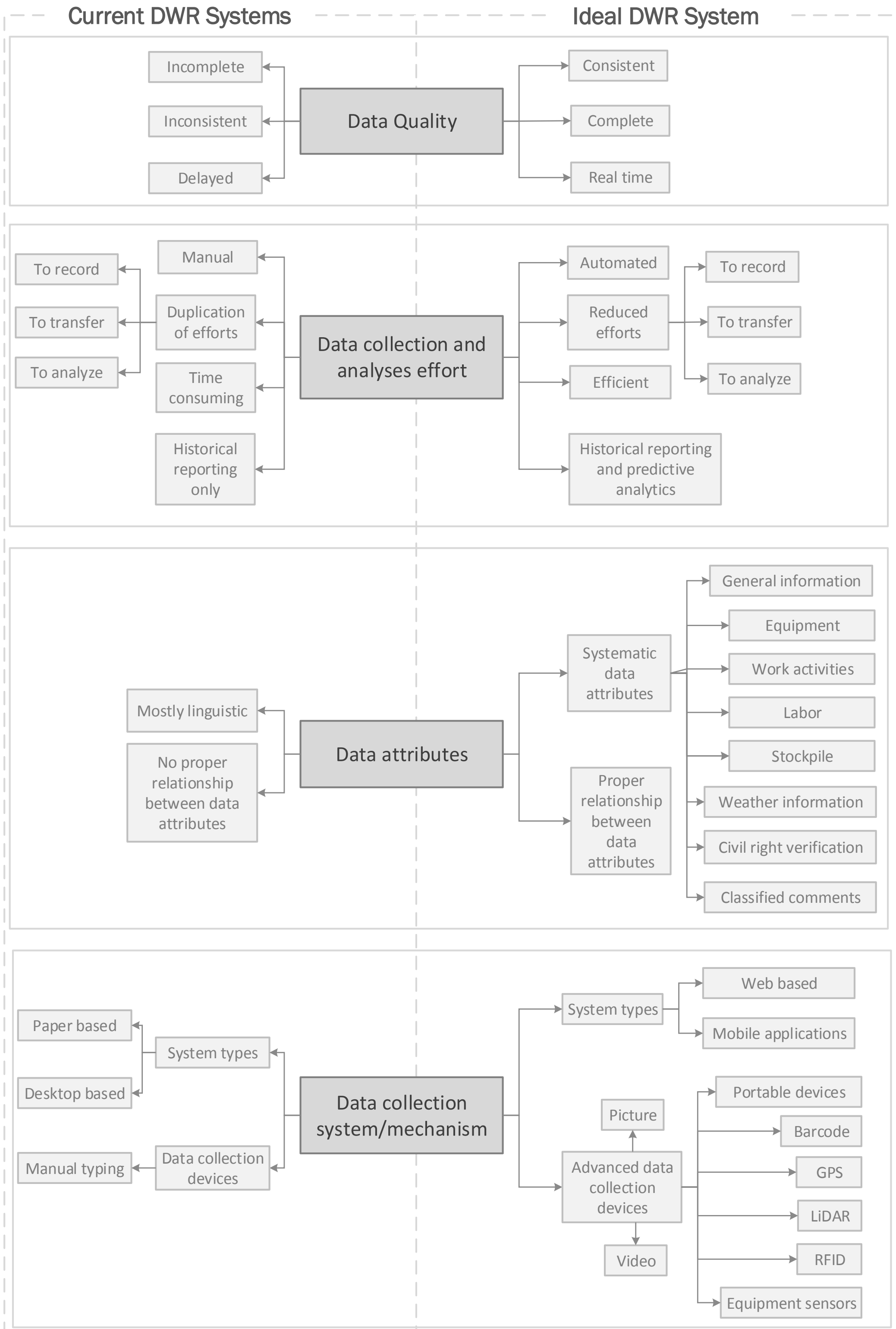

Figure E.2 Current DWR systems versus Ideal DWR system in terms of data collection

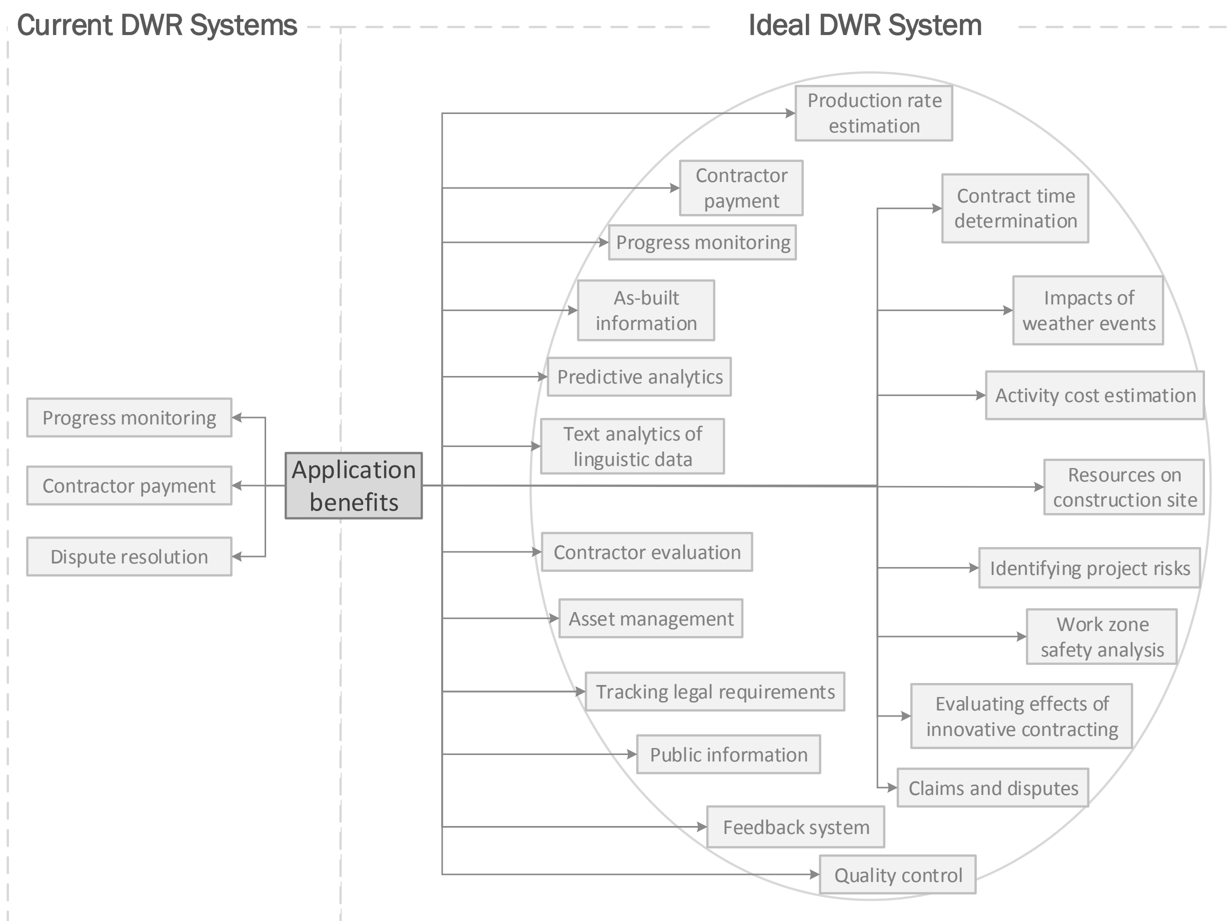

Figure E.3 Current DWR systems versus Ideal DWR system in terms of various application benefits

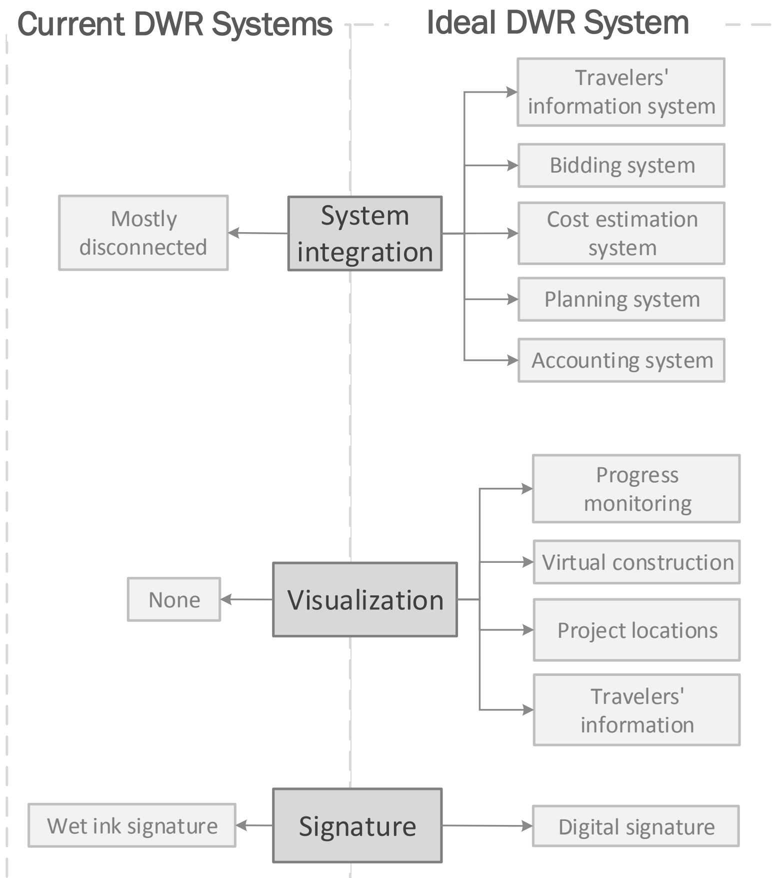

Figure E.4 Current DWR systems versus Ideal DWR system in terms of system integration, visualization, and signature

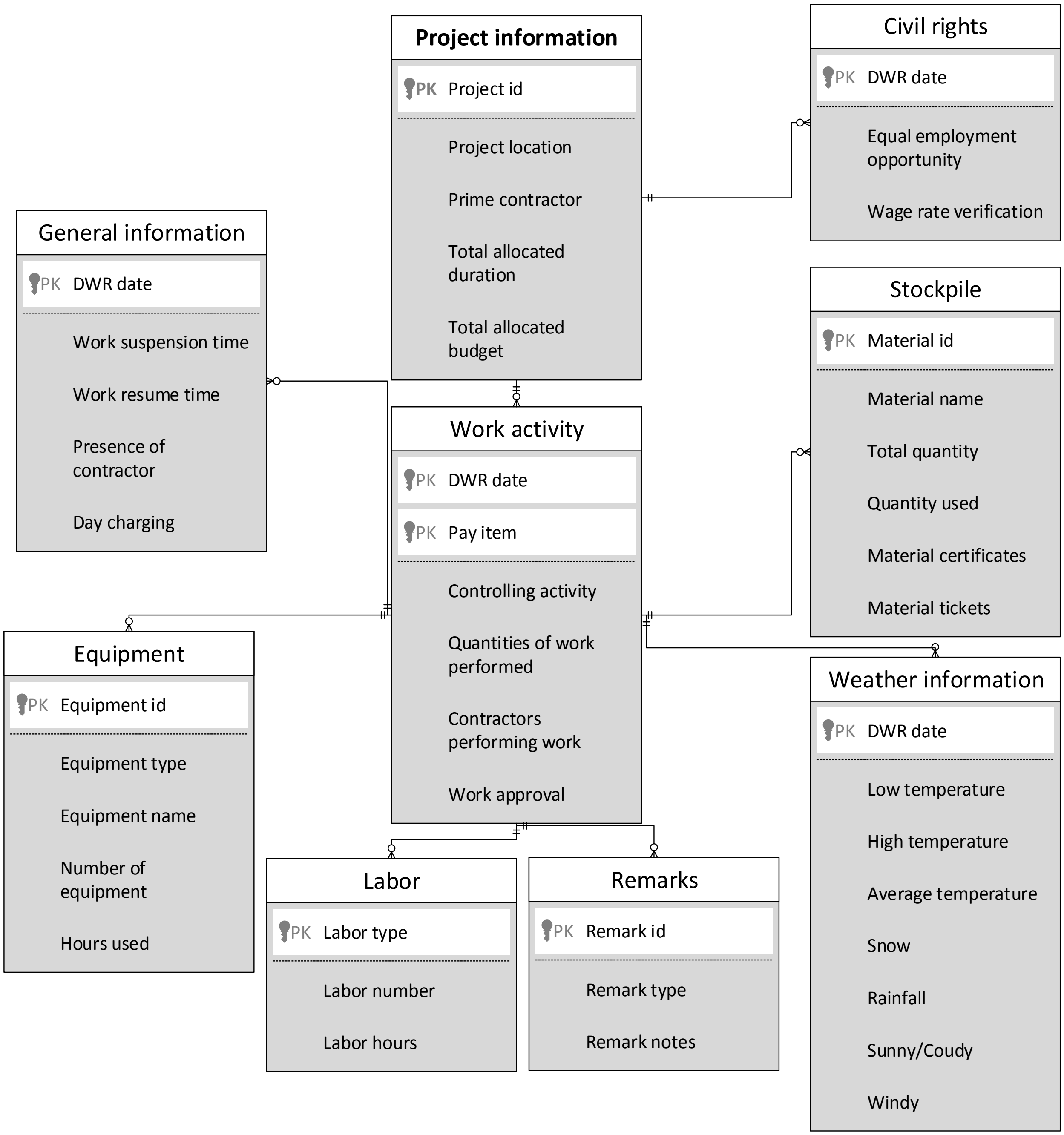

Figure E.5 Minimal Data Model for the Ideal DWR system

APPENDIX F. DWR FRAMEWORK VALIDATION QUESTIONNAIRE SURVEY

An ideal framework was developed to improve the collection and utilization of DWR data. A summary of the framework is attached in the email. We would like you to evaluate various aspects of the ideal framework on the scale of 1 (poor or strongly disagree) to 10 (excellent or strongly agree). As a representative of your state DOT and an expert in the field, your inputs would be very valuable and will be greatly appreciated.

Your name: ______________________________________

Advancement	**Score (1-10)**
This framework proposes some useful advancement over current DWR systems.	

Comments: ____

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Tackling Challenges	**Sore (1-10)**
This framework can aid in tackling current challenges (listed below) of getting benefits from current DWR systems.	
Lack of proper data attributes	
Resources limitation	
Duplication of efforts	
Technical limitations	
Current business practices	

Comments: ____

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Adaption to improve current systems	Score (1-10)
Current DWR systems can adapt some parts of the framework to improve their existing system.	

Comments:

Adaption to develop a new DWR system	Score (1-10)
The framework can be adapted to develop a DWR system if a state DOT does not have one.	

Comments:

Comprehensive	Score (1-10)
The framework is comprehensive in terms of its scope.	

Comments:

Easy to comprehend	Score (1-10)
The framework is easy to comprehend.	

Comments:

Additional comments:

What other changes would you suggest for the framework? Do you have any other ideas / opinions / comments about the framework?