

TECHBRIEF



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Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction)

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This TechBrief summarizes a program case study that highlights the transformation and automation of the Pennsylvania Department of Transportation (PennDOT) construction process through the development of advanced mobile applications, automated workflows, and their integration with collaboration tools and payment systems to improve overall efficiency. PennDOT projects significant monetary benefits due to operational and time-saving efficiencies achieved through implementation of e-Construction practices. This TechBrief provides an overview of e-Construction as a national practice, summarizes PennDOT's history and approach to technology implementation, and describes the investment and benefits realized during a 3-year period. This TechBrief aligns with the Federal Highway Administration (FHWA) research project Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction), which assesses how transportation agencies are transitioning to a more electronic/paperless project delivery system (e-Construction) and documents the costs, benefits, and challenges during the transition. It is offered as a general aid for those organizations considering starting similar programs or enhancing existing ones and provides a case study of how State transportation departments may expand their use of e-Construction practices.

Introduction

e-Construction is 1 of 12 innovations in FHWA's third round of the Every Day Counts (EDC-3) initiative. As part of the EDC-3 initiative, FHWA has initiated a research project to document the costs, benefits, and challenges of implementing e-Construction.

This case study describes PennDOT's e-Construction practices and is part of the overall research project to develop implementation guidance. This guidance will include an approach to calculating a return on investment (ROI) that agencies will then be able to tailor to their own construction program based on their specific processes.

PennDOT is considered a national leader in e-Construction, having made significant strides in transforming and automating the construction administration process, which eliminates the paper-based environment.⁽¹⁾ However, the real value realized from e-Construction is the significant gain in

process efficiencies. This TechBrief provides an overview of PennDOT's well-established processes for electronic submittals of all contract documents for the entire project construction phase through the use of collaboration tools and automated workflows using mobile technology to streamline and expedite contract inspection and administration. PennDOT's implementation of collaboration tools and mobile technology resulted in increased efficiencies—specifically, operational and time savings. Operational savings include reduction of paper, field inspection diary books, and mileage for trips to/from the project office, while time savings include improved workforce usage for field inspections.

Overview of E-Construction

Background

The construction process is traditionally paper-intensive, starting with paper plans that are used at every step of construction.

“PennDOT's e-Construction efforts are transforming our field construction inspection and management processes in all aspects of construction documentation procedures and contractor submittal reviews and approvals. This has increased efficiency which allows our inspection staff to spend more time performing their core functions of quality assurance and contract compliance verification duties, supporting our Transportation Quality Initiative. In addition, it provides for reduced errors, improved data integrity and more responsiveness to our great business partners.”

—Dan Cessna P.E.
PennDOT District Executive Construction Engineering
District 11-0¹

¹E-mail message to author, April 5, 2016.

On a design-bid-build (DBB) project, these plans are typically carried around onsite by contractors and transportation agency personnel and used to transform the project design into reality. Transportation agencies must also update the plans to match actual construction, creating “as-builts” at the end of construction. These may be completed either by the agency or the contractor, depending on the preference of the agency. As-builts, when complete, are stored in file cabinets, on microfilm, or via other media that do not tend to be easily accessible. Furthermore, during construction, transportation agencies maintain records of project work in the form of daily reports, pay record books, materials testing and acceptance reports, and a wide variety of related elements.

Typically, the contractor must meet a number of requirements in order to submit project information and records, including bill of materials, testing reports, certifications, and many other documents over the life of a project. Because most of the work during construction occurs in the field on the project site, these documents are often paper-based (as opposed to electronic) and must either be transferred to a system (requiring re-entry of the information) or remain in a paper form that is typically cumbersome and difficult to retrieve. Furthermore, this paper-intensive process means that, apart from the environmental and monetary impact of printing/paper usage, much information cannot be shared quickly among all involved parties. e-Construction offers a way to

reduce paper, streamline workflows, and increase process efficiencies.

What Is e-Construction?

FHWA defines e-Construction as a paperless construction administration delivery process that includes electronic submission of all construction documentation by all stakeholders, electronic document routing and approvals (e-signature), and digital management of all construction documentation in a secure environment, allowing distribution to all project stakeholders through mobile devices.

e-Construction can be used throughout all steps of the project delivery process, from project advertisement to final project acceptance, including the following:

- Bidding and contractor selection/contract award.
- Electronic plan documents.
- Project construction and management (including use, transfer, and approval of electronic plan sets, contractor payroll submittals, claims, and change orders).
- Project inspection and data collection.
- Project acceptance (including punch lists, as-built submittal, and entering warranty phase).
- Project closeout (including retainage release and entering warranty phase).
- Project communications (e.g., public information management or internal communications).

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- Resource tracking (e.g., equipment, personnel, fleet, etc.).

The e-Construction process includes the following:⁽¹⁾

- Electronic capture of construction data.
- Electronic submission of construction documentation.
- Increased use of mobile devices.
- Increased automation of document review and approval.
- Use of electronic signatures throughout the construction process by all parties involved.
- Secure document and workflow management accessible on any device.

Benefits of e-Construction

e-Construction practices streamline workflows and improve communication and process efficiencies while saving time and money. The process efficiencies are realized through electronic processes to access, update, and share documents and data with all involved parties, thus simplifying workflows and improving timely collaboration. The direct cost savings are realized through reduced printing, mailing, and space for document storage. The benefits of a paperless project delivery system (e-Construction) occur during both the preconstruction and post-construction project phases when plans, project details, testing, materials and location data, and a wide variety of other potential information are available to maintenance staff to plan operations, maintenance, and asset management activities.

e-Construction Information Technology (IT)

The IT infrastructure needed to support e-Construction practices includes digital signatures, digital storage, and data connectivity. Other supporting tools include hardware (e.g., computers, mobile devices, and surveying equipment) and software. An illustration of the IT infrastructure support and areas of e-Construction is provided in figure 1.

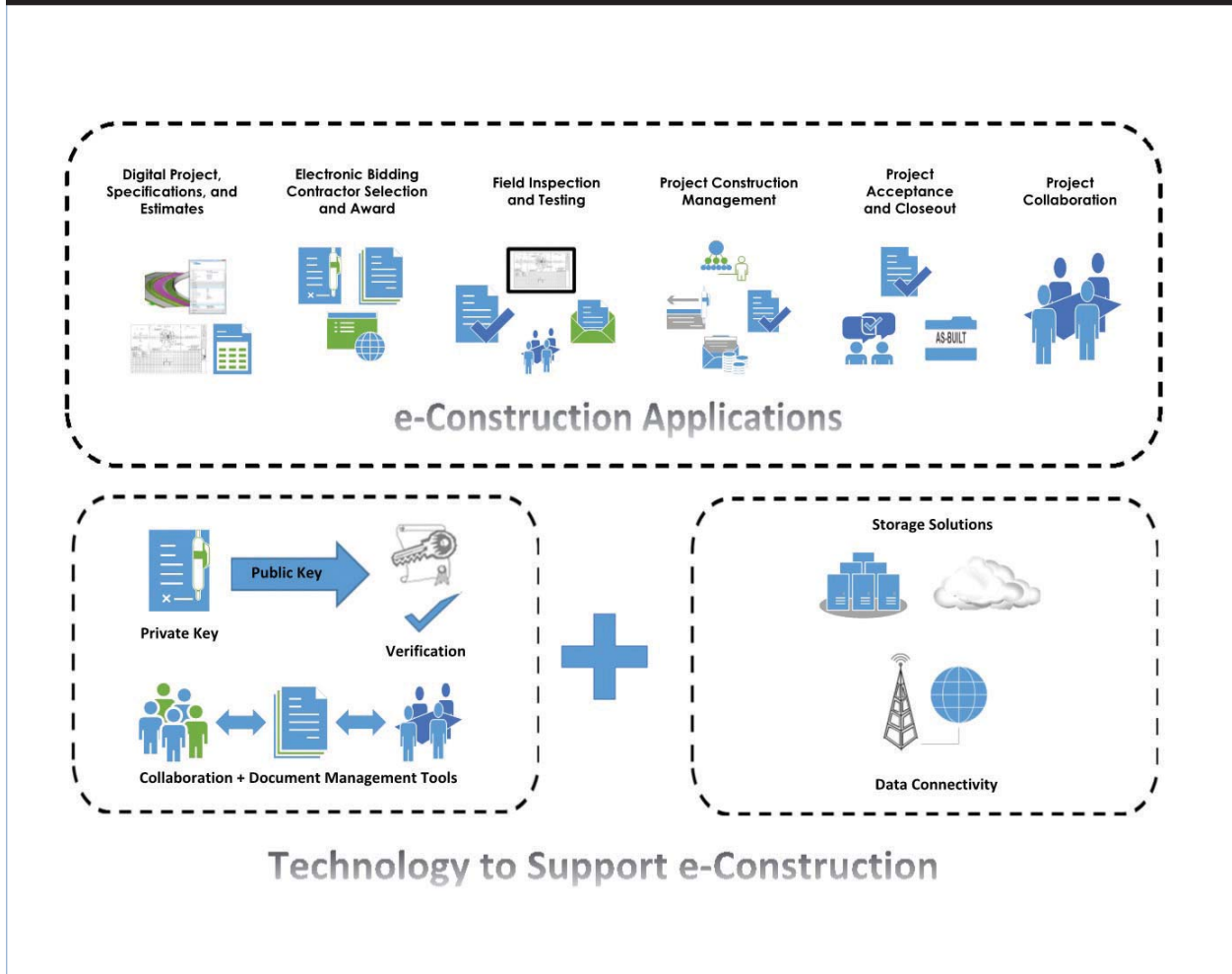
Many State transportation departments have been using e-Construction practices in at least one step of the project delivery process. Some areas of e-Construction are easier to implement than others for a number of reasons, such as fewer investment requirements, availability of commercial off-the-shelf (COTS) solutions, or well-documented processes that help facilitate a more seamless transition to a paperless environment. The maturity and implementation approach of e-Construction practices vary from agency to agency. However, the most maturity has been demonstrated in the bidding and contractor selection/contract award phase of the project delivery process.

PennDOT e-Construction Practices and Benefits

Organizational Overview

PennDOT is directly responsible for approximately 40,000 roadway mi and 25,000 bridges. As of April 2016, the agency has a total of 763 active projects valued at a total of approximately \$6 billion; 596 of those projects are DBB, and 167 of those projects are design-build.

Figure 1. e-Construction practices and tools to support them.



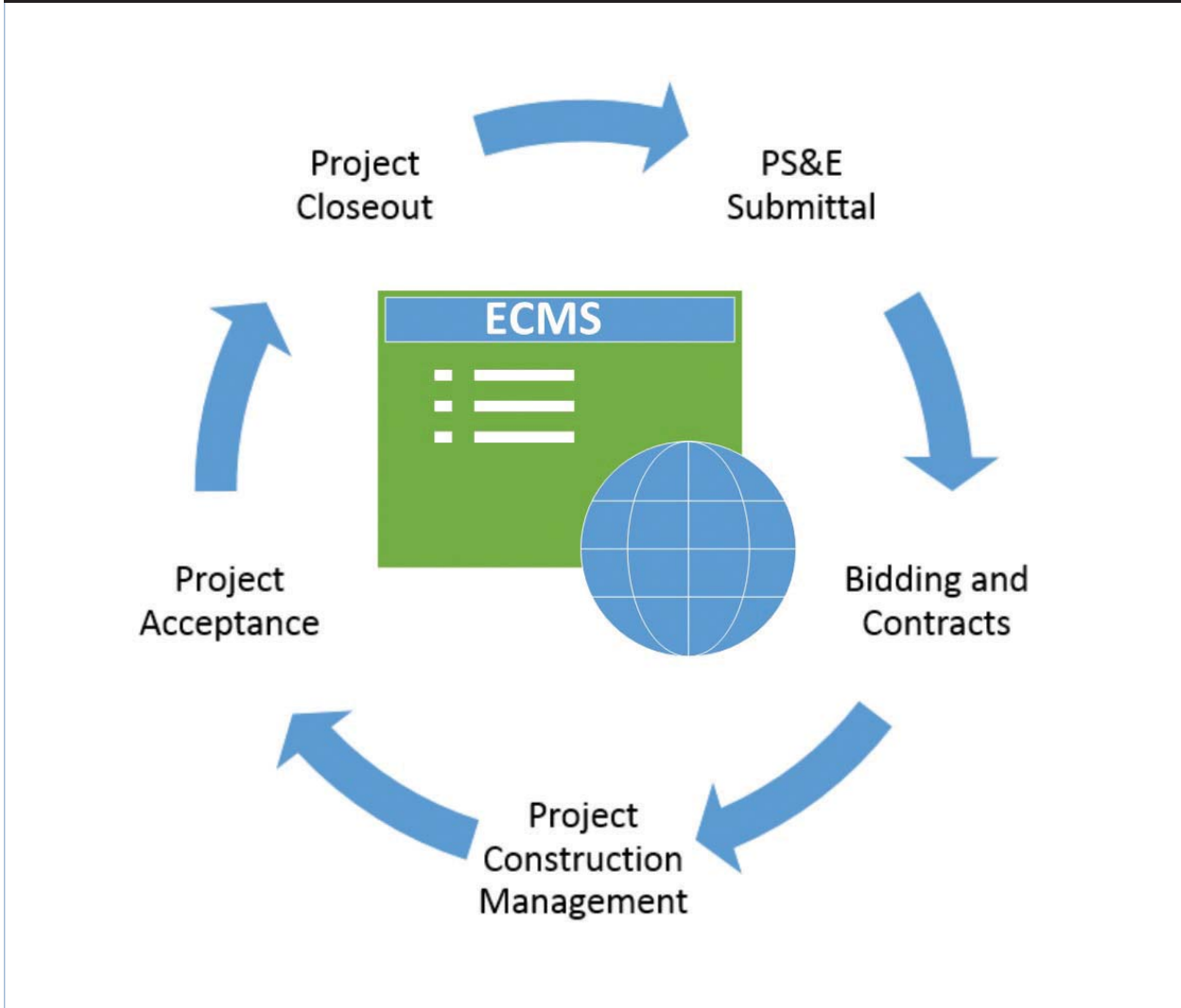
The Highway Administration organization within PennDOT oversees the project-delivery process and is headquartered in Harrisburg, PA. The headquarters office provides policy support to the 11 engineering districts responsible for delivering the construction program.

Current e-Construction Practices

PennDOT transitioned to paperless administration of contractual documents and for the documentation of construction inspections in 2003. PennDOT uses an in-house-developed, Web-based application

known as the Engineering and Construction Management System (ECMS) as the platform to support its e-Construction practices throughout the agency. ECMS is the key system used throughout the project-delivery process—from advertisement to project closeout—to manage all contractual documents used for bidding, contract approvals, work order approvals, audits, and construction documentation. Other current systems supporting e-Construction practices within the agency are built to easily integrate with ECMS, as shown in figure 2.

Figure 2. PennDOT ECMS for supporting e-Construction practices.



Plans, Specifications, and Estimates (PS&Es)

PennDOT’s engineering districts are responsible for plan development production of the projects in each geographic region. Plan development for roadway and bridge design is accomplished using computer-aided drafting and design (CADD) products. PennDOT structural and roadway designers have been developing contract drawings based on a variety of parametric design software since the mid-1990s. PennDOT has standardized on the

Bentley MicroStation® CADD platform and uses Bentley’s InRoads® as the civil design software to create three-dimensional (3-D) corridor models. These 3-D corridor models are the basis for the production of contract drawings, which generate the electronic plan sheets. PennDOT does not currently have a process to electronically sign and seal plan sheets. Title sheets require professional signing and sealing and must use ink signatures and physical seals before they are scanned into portable document format (PDF) documents. All other plan

sheets are printed directly into PDF from the CADD drawing. All PDF documents are uploaded to ECMS for the advertisement and bidding process. Although PennDOT has been sharing 3-D models with contractors post-award since 2003, in January 2014, it became department policy to develop 3-D models primarily, but not exclusively, for moderate to complex construction projects. These digital design files are shared as “for information only” reference documents with contractors during the pre-bid phase via ECMS. Today, PennDOT shares surface and geometry files in LandXML, a non-proprietary data standard used in the transportation industry to support 3-D data sharing.⁽²⁾ LandXML is overseen by an industry consortium of partners. The PS&E workflow is illustrated in figure 3.

Bidding and Contractor Selection/Contract Award

As previously stated, PennDOT relies on ECMS as a key tool to support e-Construction, which starts with the bidding and contract process. During

the advertisement phase, ECMS is used for electronic bidding, solicitation for consultant professional services, contractor and consultant selection, and contract execution. Also, this system can be used to view all construction project information and documents, such as PS&E documents, contract agreements, and any other electronic documents requiring agency approval or certification.

ECMS employs user authentication protocols to track every transaction made in the system, which meets the State requirements for contract activity. The ECMS approval process is used in lieu of digital signature technology for contractual documents. A screenshot of the log-in screen is shown in figure 4.

Project Construction and Management

Once a contract has been awarded, ECMS is used by the district construction personnel to administer the project. Because ECMS is a highly secured system based on user authentication for accessing project data, construction staff can use it to add information to the system as project construction

Figure 3. PennDOT’s workflow for developing electronic plans.

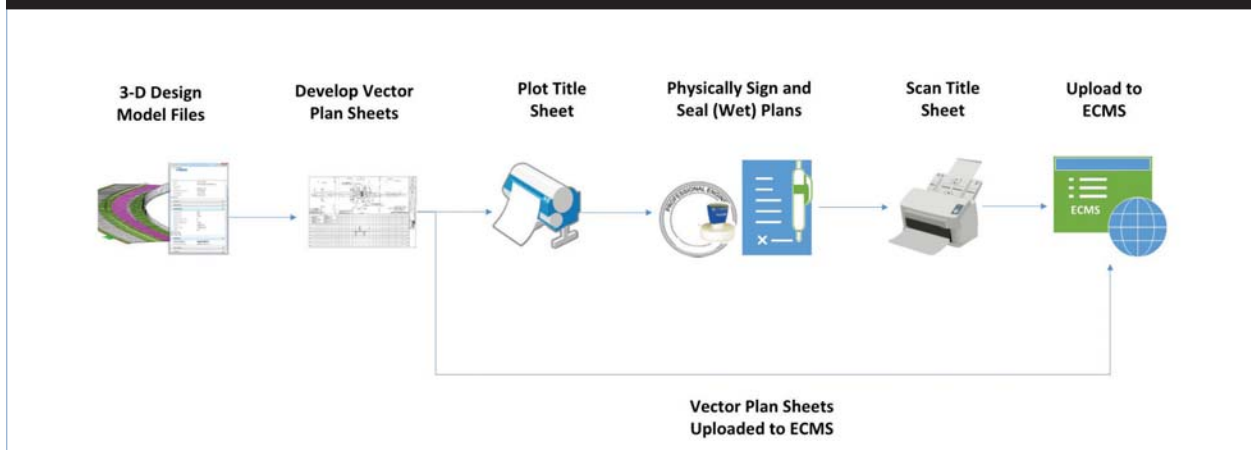
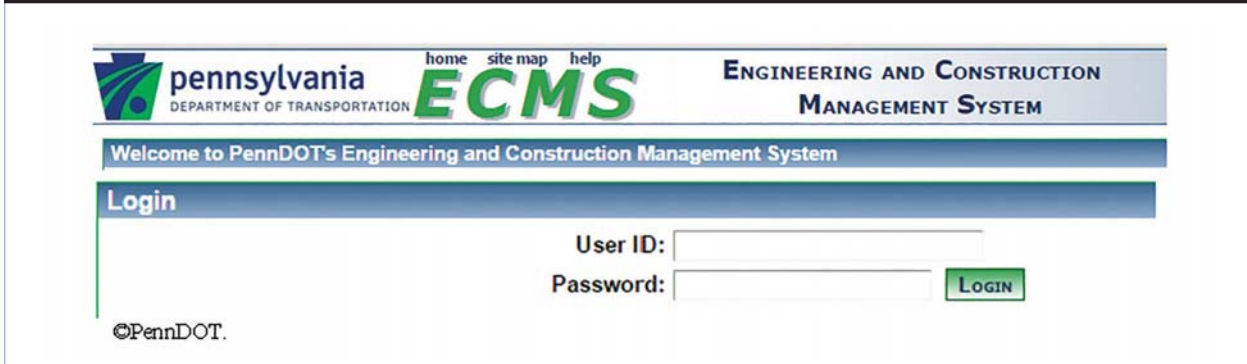


Figure 4. Secure user authentication for ECMS.



continues. Construction personnel add estimates, work orders, site activities, invoices, and payment information. All approvals and documentation of project site activities (PSAs) are completed through ECMS using automated workflows, but other systems are used for project collaboration, report creation, and record storage and retention. These systems are described as follows:

- PennDOT Project Collaboration Center (PPCC) is a modified version of Microsoft® SharePoint® used for submitting documents for review. This system provides better collaboration at all levels of the agency and with business partners. Also, it provides more efficient access to information, true multiuser collaboration with versioning, check-in/check-out ability, an audit trail, retention policies, the ability to add metadata, and use of workflows for business processes. Most important, this system provides construction document retention while complying with “right-to-know” State laws. This system is integrated with ECMS, and it is the system used to share files, photos, and training materials.
- Electronic Document Management System (EDMS) is the system PennDOT uses for electronic archival of project documents once the project is no longer active. ECMS connects to EDMS for accessing the files already stored in the system. This system is integrated with ECMS and is currently being integrated with PPCC.
- The Construction Document System (version 3) (CDSv3) was created as a companion application to ECMS for construction management and inspection of projects. The main purpose of CDSv3 is to document PSAs and contractor payments, but it is also used to create reports with data retrieved from ECMS.

Project Inspection and Testing

Until recently, PennDOT relied on a combination of paper-based and electronic documentation for project inspection and testing. Inspectors would record PSAs in the field using paper diaries that would then have to be entered into the Construction Document System (CDS) once the inspector returned to the office. CDS is the system

used to record PSAs from the diaries of the field inspector or by direct entry. PennDOT recognized the need for better integration and accessibility of construction documents and improved mobility. A technology project was introduced in 2013 to upgrade CDS to the same technology platform upon which ECMS was built. Upgrades to both ECMS and CDS were guided by the following three essential business drivers:

- Accessibility to data, such as work orders, estimates, PSAs, and audits via the Web.
- Accessibility to project forms (currently stored in paper form in offsite project files).
- Increased field inspection mobility.

To meet the business needs of construction management staff, the following services needed to be included as part of the upgrades:

- **Digitization of forms and documents:** Scanning, indexing, storage, and retrieval of paper images and electronic documents.

- **Increased data accessibility:** Capturing and viewing information such as dates of contracts, contractors, work orders, estimates, PSAs, audits, field tests, and suppliers.
- **Establishment of new workflows:** Tracking, documentation of logging of approvals, notifications, and alerts.
- **Increased security:** Authentication and authorization of PennDOT staff, consultants, and contractors.

CDSv3 was the resulting product of the system upgrade, and it was launched in August 2014. Today, construction inspection is performed in the field using mobile devices to record PSAs directly into CDSv3. Also, submittal of estimates and work orders can be completed directly from the field and uploaded into ECMS for approvals using a secure Web interface through mobile devices. The screen interface of the CDSv3 PSA module is shown in figure 5.

PennDOT selected the Apple® iPad® to use for mobile inspections because the agency's IT group determined that the iPad® offered a higher level of security for

“The biggest benefit of an electronic construction documentation system, such as PennDOT’s CDSv3, is its mobility for accessing reports and other projects documents in the field through a Web interface and a mobile device.”

—Lori Miles
Construction Support Manager
Engineering District 11-0²

²Interview with author, January 8, 2016.

Figure 5. PSA documentation through CDSv3.

PSA - Inspector Hours						
Start Time	Quit Time	Hours	Pay Code	L/C Code		
No records found.						
PSA - Weather and Work Suspended						
Time	Temperature	Weather Condition	Work Suspended			
No records found.						
PSA - Comment						
No records found.						
PSA - Contractor						
No records found.						
PSA - Work Items						
Item	Type	Fund SR / Section	Plan Station	Actual Location	Quantity	Unit of Measure
No records found.						
Project Site Activity Documents						
Attachment Title	Category	File Type	File Size	Upload Date	Description	
No records found.						

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accessing the systems directly than any other device. Several mobile computing (MC) applications have been developed internally and are available on PennDOT-issued iPads®. These applications allow the following:

- Enable inspectors to edit engineering drawings at the construction site and electronically transmit them for review and approval.
- Ensure project documents are always up to date.
- Automatically calculate quantities of concrete and bituminous material delivered to the site.
- Enter dimensions directly.
- Automatically validate whether the supplier of the materials is authorized.
- Document materials testing in the field.
- Automatically calculate payment

information and transmit this information to the payment system.

- Document and resolve discrepancies using the automated workflow that is provided through the construction project automation.

The mobile applications are summarized in figure 6.

PennDOT’s use of electronic documentation, collaboration tools, and mobile technology has redefined construction processes by doing the following:

- Enabling team collaboration.
- Providing access to necessary information for decision making in the field.
- Improving the quality of construction data and documentation.
- Expediting the approval and payment processes.

Figure 6. Construction mobile applications for field inspection and testing.



MC-Documents – Access to project reference documents

MC-PSA – Direct data entry of daily activity including complex calculations (cubic yards) for materials delivered. Offers pre-populated forms with project and inspector data, saves "favorites" (e.g. contractor labor and equipment). Automated payment calculations and entry of payment information into payment system.

MC-Punchlist – Document and share construction site discrepancies with other inspector and contractor. Tracks workflow of the correction and final resolution to discrepancies. Allows for file attachments (photos, etc.).

MC-Force Account – Data entry for recording contractor labor hours, equipment used, and materials used daily.

MC- Consultant Hours and Mileage –Data entry for recording daily consultant hours (construction inspection staff) and mileage.

MC- Concrete Book – Used for documentation of field concrete testing activities.

System Integration

- ECMS
- CDS
- PPCC

“Mobile technology has enabled PennDOT to completely transform and automate the labor-intensive paper-based processes and calculations of the past. Through our mobile development efforts, we have connected over 1,500 previously disconnected construction inspectors. The mobile technology has been a major disruptor, enabling us to provide end-to-end automation of construction processes.”

— Rebecca Bickley
Project Development and Delivery Director
PennDOT Bureau of IT³

³Interview with author, April 4, 2016.

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- Providing one single source of truth for construction documents.

In addition, the use of automated workflows has significantly improved efficiency and overall program effectiveness while allowing construction staff to focus on construction oversight.

Project Acceptance and Closeout

Similar to many other agencies, PennDOT still relies on paper-based as-built records and a combination of manual and some automated tracking of warranty items. However, PennDOT's recent upgrade of its construction management system included a mobile application to document punchlists and final inspection records. The

MC-Punchlist mobile application has the following two sections: (1) the Physical Work section and (2) the Required Documents section (shown in figure 7).

When the final inspection is held, a final inspection punchlist is created, and all unresolved items from the ongoing project punchlist are transferred to the final inspection punchlist. A list of attendees from the final inspection can be documented on the final inspection punchlist.

Future Upgrades

The original system upgrade was implemented in August 2014, and the second release of enhancements was launched in March 2015. Future enhancements will

“From FHWA’s perspective, e-Construction (specifically ECMS) has revolutionized the way we interact with PennDOT. We can now instantly see real-time project information, gather data, conduct reviews and approve actions like never before. This ability has saved us an incredible amount of time and paperwork to review and approve projects. PennDOT transforms itself through implementing innovation.”

— Tony Mento
Director of Technical Services
FHWA PA Division⁴

⁴E-mail to author, April 19, 2016.

Figure 7. Examples of punchlist data fields.

The figure shows three examples of punchlist data fields:

- PHYSICAL WORK:** A table with three columns: ITEM/ACTION, DATE COMPLETED, and DEPARTMENT VERIFICATION.
- REQUIRED DOCUMENTS:** A table with three columns: ITEM/ACTION, DATE COMPLETED/RECEIVED, and DEPARTMENT VERIFICATION.
- FINAL INSPECTION FORM:** A form with fields for S.R., Sec., County, and District; Contract No. and Contractor; a date field for "A Final Inspection of the above project or substantial project section was held on"; and an ATTENDEES field.

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continue to be scheduled as part of ongoing software maintenance to keep the systems functional and provide added value based on user input. The following enhancements are scheduled:

- Material source of supply automatic approvals. (Phase I was implemented in July 2016, and phase II is scheduled for 2017.)
- Force account documentation and cost automation. (User acceptance testing has started, and phase II implementation started in early 2017.)
- Consultant mileage and hours (scheduled for June 2017).
- PennDOT payroll and expense voucher automation (scheduled for 2018).

Benefits and Costs

Implementation Development and Support Costs

PennDOT estimates a total cost of \$9.06 million for the development and deployment of CDSv3, PPCC, and MC software applications. The costs were calculated based on the actual number of labor hours required for development and support of the project multiplied by a blended hourly rate, as illustrated in table 1. Costs for hardware (i.e., mobile devices) and training are not included in these calculations.

Benefits

PennDOT estimates an annual operational savings of \$23.4 million, which includes \$5.9 million from its construction documentation

Table 1. Costs for development and support of PPCC, CDSv3, and MC applications.

Project	Blended Hourly Rate	Number of Labor Hours	Total Cost
PPCC (initiated in October 2011)	\$100	46,486	\$4.65 million
CDSv3 (initiated in August 2012)	\$110	24,973	\$2.74 million
MC applications (initiated in July 2013)	\$124	13,419	\$1.67 million
Total			\$9.06 million

(CDSv3) and \$17.5 million from its MC applications initiatives. The benefits for PPCC are still being evaluated. The benefits calculated were based on the following two types of benefits:

- **Operational savings (CDSv3 only):** The elimination of paper-based methods for conducting inspection documentation and construction administration and cost avoidance such as for storage and materials.
- **Employee time savings (CDSv3 and MC applications):** The time savings of staff from reduced driving between the field and the office and transcribing data from field books to electronic systems, auditing, printing, mailing, filing, and searching for paper documents. Other time savings include automatic calculation of quantities and payments, automated validation of suppliers and approved materials, ability to edit design documents, and use of automated workflows.

Table 2 summarizes the anticipated benefits for CDSv3.

Table 3 summarizes the assumptions used for calculating the anticipated benefits for MC. MC benefits were calculated based on a unit cost savings per hour multiplied by the number of State/consultant employees and the total number of hours saved per year. The hours saved per year assumes a savings of 1.5 h per inspector (380 PennDOT inspectors and 1,200 consultant inspectors) for 160 d per year.

Table 2. PennDOT anticipated benefits for CDSv3 implementation.

Anticipated Benefit Stream	Unit Cost	Savings per Year
Operational savings—amount of field inspection books purchased	\$2.85/unit	\$52,676
Operations savings—reams of paper	\$11.00/unit	\$78,694
Operational savings—inspector-in-charge travel expenses	\$0.55/mi	\$83,567
Operational savings—auditor travel expenses	\$0.55/mi	\$125,910
Operational savings—project boxes to shred	\$0.10/lb	\$7,440
Operational savings—project boxes purchased	\$3.25/box	\$9,300
Employee time savings 1a—project staff documentation entry (PennDOT)	\$51.48/h	\$1,176,503
Employee time savings 1b—project staff documentation entry (consultant)	\$61.71/h	\$3,151,999
Employee time savings 2a— inspector-in-charge’s travel time to process project site activities, estimates, and work orders	\$57.00/h	\$489,334
Employee time savings 3—auditing	\$44.61/h	\$638,280
Employee time savings 4—organizing/destroying project boxes	\$51.48/h	\$12,276
Employee time savings 5a—automation of asphalt adjustment (PennDOT)	\$51.48/h	\$13,168
Employee time savings 5b—automation of asphalt adjustment (consultant)	\$61.71/h	\$15,784
Employee time savings 6a—automation of diesel fuel adjustment (PennDOT)	\$51.48/h	\$26,562
Employee time savings 6b—automation of diesel fuel adjustment (consultant)	\$61.71/h	\$31,841
Total		\$5,913,334

Table 3. PennDOT assumptions for anticipated benefits for mobile computing implementation.

Anticipated Benefit Stream	Unit Cost	Number of Labor Hours Saved	Savings per Year
Employee savings 7A—anticipated increased efficiency through use of mobile computing (PennDOT)	\$36.66/h	91,200	\$3,343,392
Employee savings 7A—anticipated increased efficiency through use of mobile computing (consultants)	\$49.17/h	288,000	\$14,160,960
Total			\$17,504,352

Calculating ROI

While many agencies, including PennDOT, have started to quantify the costs and cost savings of their e-Construction initiatives, they have noted the challenges and lack of a consistent method for measuring cost-benefit data and calculating an ROI. Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction) has developed a preliminary approach for calculating an ROI. This approach will enable agencies to calculate a cumulative net benefit and determine what the breakeven year will be after initial system implementation is complete. The approach is as follows:

1. Identify an evaluation period.
2. Identify benefit streams that will be realized from e-Construction initiatives.
3. Estimate the annual savings of each benefit stream (as a percentage of the annual construction program).
4. Identify the percentage of anticipated benefits that will be realized annually over the evaluation period (e.g., 5 or 7 years) for each benefit stream.
5. Identify all cost components.

6. Identify base costs for each cost component.
7. Identify the percentage of costs that will be incurred annually over the evaluation period for each cost component.

The net benefit for each year of the evaluation period will be the annual ROI, and the net benefit for all years of the evaluation period will be the ROI for the evaluation period.

Preliminary (quantifiable) benefit streams that have been identified include the following:

- Increase in the overall efficiency and effectiveness of the delivery of the agency’s construction program by streamlining and standardizing key processes (e.g., faster review and approvals).
- Reduced use of paper, printing, mailing, and scanning.
- Reduced storage, elimination of leased buildings/rental office space, or increased effective use of office space (e.g., converting file cabinet, storage, and plotter space to conference room space or additional offices).

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- Increased use of existing staff.
 - Reduced risk for error (including data entry errors, lost documentation, reduced errors in bid submittals, etc.).
 - Reinvestment opportunity from annual savings from faster project delivery.
 - Reinvestment opportunity from cost avoidance from increasing the number of contracts awarded to low bidders.

Cost components of e-Construction implementation include the following:

- Pre-implementation planning consultant (if applicable).
- COTS software licenses.
- COTS software maintenance.
- Systems integration services to configure, test, deploy, and support the new system.
- Managed services support following implementation.
- Hardware and other technical infrastructure.
- Hardware and infrastructure maintenance.
- Hardware refresh.
- Agency staff cost during project.
- Agency staff cost to support system ongoing.
- Systems integration services for upgrade.
- Contractor compliance.
- Training.

This approach will be refined in subsequent tasks of the Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction) research project, with input from State transportation departments.

Challenges and Lessons Learned

The biggest challenge that PennDOT faced when implementing multiple e-Construction initiatives was communication. A tremendous amount of coordination was required to ensure that all IT projects supporting the upgrade were aligned with the goals, business requirements, and schedule. Also, because there were different teams working on different application development, it was important that programming changes in one application did not affect the overall system. Communicating this ongoing effort to all involved parties was a challenge. However, having a direction to guide the project and the support of IT and management staff were both key success factors in achieving the project goals.

PennDOT uses a business-driven approach to keep up with technology changes. It follows a strategic IT process and project prioritization using an agile project management approach. Because there were multiple application upgrades and software developments, the same project manager was assigned to the CDSv3 and PPCC projects. Having the same project manager provided consistent coordination to ensure active engagement among the districts, the central office, and the development team at every level of the multiple projects. Also, a program manager was assigned to the

mobile application development team to oversee product deployment of the mobile applications. The program manager provided an additional layer of oversight and coordination for release dates and user acceptance testing. In addition, the program manager was in charge of the “train-the-trainer” approach training program, which was well received and resulted in great success.

Conclusion

Investing in e-Construction initiatives can be expensive because it is a technology-driven practice that includes ongoing system upgrades and procurement of newer technology. Although significant anecdotal evidence shows how e-Construction has improved the project-delivery process, actual benefits, costs, and ROI have not been systematically documented, which could be the result of the time it takes to realize the benefits and the challenges of quantifying benefits. There is, however, strong interest among State transportation departments to develop a standardized calculation.

PennDOT’s approach to calculating the cost-benefit of e-Construction is based on the reduction in paper, printing, mailing of documents, and staff efficiencies using mobile technology for field inspections. A few other agencies have also estimated the cost-benefit of e-Construction practices based on a similar approach. e-Construction investment should be calculated on the basis of paper-based environments and processes for specific activities within a transportation agency to develop a baseline

against which cost savings resulting from automation of processes can be measured.

The cost-benefit calculation of PennDOT’s e-Construction initiative was based on the iterative software development process, which had multiple deployments between 2012 and 2015. The total investment during this timeframe to develop the collaboration tools and mobile applications to support e-Construction was \$9.06 million. Also, PennDOT estimates a continued annual software maintenance cost of \$27,000. These costs are entirely based on software development and technical support using internal IT staff and do not include the cost of mobile devices or data services for the devices. PennDOT estimates that its investment in e-Construction will produce a savings of \$23.4 million per year after full implementation. A summary of the estimated costs and benefits for the agency’s e-Construction program is shown in figure 8.

PennDOT estimates a conservative time savings of 1.5 h per inspector per day and an additional savings of \$357,587 per year in operational costs. Operational costs were calculated based on the annual expenditure for field inspection diary books, paper used for printing, shredding of documents, paper boxes to store project documents, and travel expenses for miles driven from the field to the office and vice-versa. PennDOT’s cost-benefit analysis confirms that the benefits that can be realized from e-Construction practices are large and are the result of process efficiencies, which are critical for improving workforce use.

Figure 8. PennDOT's estimated costs and benefits for the e-Construction program.

Annual construction program:	\$6 billion
Development and support cost:	\$9.06 million
Annual maintenance cost:	\$27,000
Annual savings:	\$23.4 million

Addressing Challenges and Return on Investment (ROI) for Paperless Project Delivery (e-Construction) will help fill the benefits documentation gap and provide guidance for agencies on implementing a successful e-Construction process. Phase II of the project will focus on detailing opportunities for areas of improvement for e-Construction, assessing the feasibility of these opportunities, and preparing guidance for agencies. However, because many agencies noted the challenges and lack of a consistent method for measuring cost-benefit data, a greater emphasis will be placed on both preparing an ROI template for documenting benefits and costs as well as assisting agencies with documenting the benefits and costs through a more involved data-gathering process. This process will use not only data that can be obtained from the agencies' past projects but also a more involved/structured collection of benefits and cost data on ongoing or future projects. Agencies will then be able to tailor

the information to their own construction program based on their specific processes using the ROI template that is developed.

References

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Researchers—This study was performed by WSP | Parsons Brinckerhoff (DTFH61-14-C-00045).

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Key Words—e-Construction, construction inspection, construction management, digital data, mobile devices, paperless workflows, paperless environment, PennDOT.

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