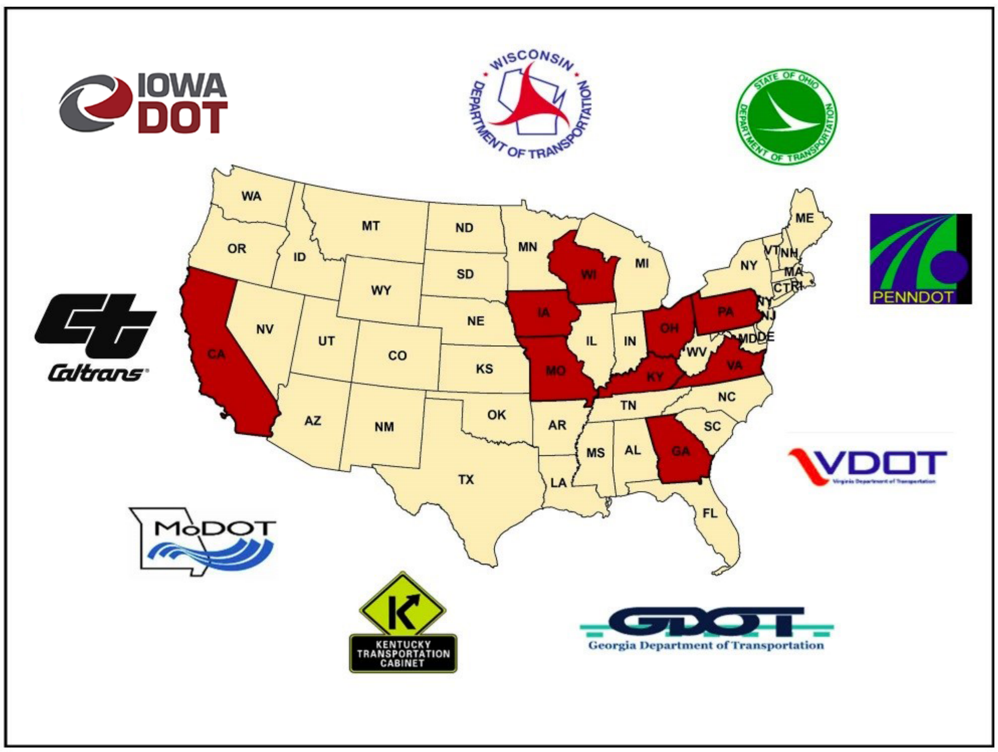
Report of the 4th Workshop for Technology Transfer for Intelligent Compaction Consortium

October 27–28, 2015



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CEER CENTER FOR EARTHWORKS ENGINEERING RESEARCH

IOWA STATE UNIVERSITY
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About the Center for Earthworks Engineering Research

The mission of the Center for Earthworks Engineering Research (CEER) at Iowa State University is to be the nation's premier institution for developing fundamental knowledge of earth mechanics, and creating innovative technologies, sensors, and systems to enable rapid, high quality, environmentally friendly, and economical construction of roadways, aviation runways, railroad embankments, dams, structural foundations, fortifications constructed from earth materials, and related geotechnical applications.

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16. Abstract

This document summarizes the discussion and findings of the 4th workshop held on October 27–28, 2015 in Frankfort, Kentucky as part of the Technology Transfer Intelligent Compaction Consortium (TTICC) Transportation Pooled Fund (TPF-5(233)) study. The TTICC project is led by the Iowa Department of Transportation (DOT) and partnered by the following state DOTs: California, Georgia, Iowa, Kentucky, Missouri, Ohio, Pennsylvania, Virginia, and Wisconsin.

The workshop was hosted by the Kentucky Transportation Cabinet and was organized by the Center for Earthworks Engineering Research (CEER) at Iowa State University of Science and Technology. The objective of the workshop was to generate a focused discussion to identify the research, education, and implementation goals necessary for advancing intelligent compaction for earthworks and asphalt. The workshop consisted of a review of the TTICC goals, state DOT briefings on intelligent compaction implementation activities in their state, voting and brainstorming sessions on intelligent compaction road map research and implementation needs, and identification of action items for TTICC, industry, and Federal Highway Administration (FHWA) on each of the road map elements to help accelerate implementation of the technology. Twenty-three attendees representing the state DOTs participating in this pooled fund study, the FHWA, Iowa State University, University of Kentucky, and industry participated in this workshop.

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Report of the 4th Workshop for Technology Transfer for Intelligent Compaction Consortium (TTICC) Transportation Pooled Fund Study Number TPF-5(233)

October 27–28, 2015

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Preface

This document summarizes the discussion and findings of the 4th workshop held October 27–28, 2015 in Frankfort, Kentucky, as part of the Technology Transfer Intelligent Compaction Consortium (TTICC) Transportation Pooled Fund (TPF–5(233)) study. The TTICC project is led by the Iowa Department of Transportation (DOT) and partnered by the following state DOTs: California, Georgia, Iowa, Kentucky, Missouri, Ohio, Pennsylvania, Virginia, and Wisconsin. The workshop was hosted by the Kentucky Transportation Cabinet and was organized by the Center for Earthworks Engineering Research at Iowa State University of Science and Technology.

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Acknowledgments

The Center for Earthworks Engineering Research (CEER) at Iowa State University of Science and Technology gratefully acknowledges the Kentucky Transportation Cabinet (KYTC) for hosting the workshop and the support of the following participating state Departments of Transportation (DOTs): California, Georgia, Iowa, Kentucky, Missouri, Ohio, Pennsylvania, Virginia, and Wisconsin. Sharon Prochnow and Denise Wagner of the CEER provided administrative support in organizing and executing the workshop. The CEER also sincerely thanks the following individuals for their support of this workshop:

Planning Committee

KYTC ▪ Adam Ross
Intrans, Iowa State University ▪ Denise Wagner
CEER, Iowa State University ▪ David White, Pavana Vennapusa

State/Federal Agency Participants

Georgia DOT ▪ Ian Rish, Alfred Casteel
Iowa DOT ▪ Melissa Serio, Stephen Megivern
KYTC ▪ Adam Ross, Jeremiah Littleton, Jason Siwula, William Nolan, Erika Drury, Mark Walls, Matt Looney, David Hunsucker, Clark Graves
Missouri DOT ▪ William Stone, Kevin McLain
Ohio DOT ▪ Stephen Slomski
Pennsylvania DOT ▪ Daniel Clark
Virginia DOT ▪ Edward Hoppe
FHWA ▪ Darrin Grenfell, Michael Arasteh

Other Workshop Participants

Plantmix Asphalt Industry of Kentucky ▪ Brian Wood

Executive Summary

On October 27–28, 2015, the Kentucky Transportation Cabinet (KYTC) hosted the 4th workshop for the *Technology Transfer for Intelligent Compaction Consortium* (TTICC), a Transportation Pooled Fund (TPF–5(233)) initiative designed to identify, support, facilitate, and fund intelligent compaction (IC) research and technology transfer initiatives. The following were the key objectives of the workshop:

- Review and exchange experiences of state DOTs in implementing IC for earthwork and Hot Mix Asphalt (HMA)
- Review the existing IC specifications
- Facilitate a collaborative exchange of information between state DOTs, the Federal Highway Administration (FHWA), and industry to accelerate effective implementation of IC technologies
- Update the IC roadmap for identifying key research/implementation/education needs, and action items for the TTICC group, the FHWA, and industry

The workshop's attendees—representing seven state DOTs, the FHWA, Plantmix Asphalt Industry of Kentucky, and Iowa State University—reviewed the current IC specifications, discussed recent IC pilot specifications implemented by state DOTs or demonstration projects conducted by state DOTs, discussed the challenges being experienced by the DOT personnel during implementation and potential solutions, and voted and brainstormed IC research, implementation, and educational needs.

A key outcome of the workshop was the evaluation and update of the IC Road Map, a prioritized list of IC technology research/implementation needs initially created in a 2008 IC workshop meeting and updated in the previous workshops. The top three IC research/implementation needs are now (1) data management and analysis, (2) sustainability and return of investmen, and (3) correlations between IC and in situ test measurements. The revised IC road map is presented in Table 1. After updating the IC roadmap, the group identified action items for the TTICC group, the FHWA, and industry for advancing the top three road map elements.

This forum served to facilitate information exchange and collaboration and developing a list of action items to advance and accelerate implementation of IC technology into earthwork and asphalt construction practice and developing a short list of items that the TTICC team can use to help advance the IC road map research/implementation priorities. An IC workflow process has been developed as part of this effort linking the design, construction, and testing phases of a project.

Table 1. Prioritized IC technology research/implementation needs – 2015 TTICC workshop

Prioritized IC/CCC Technology Research/Implementation Needs

1. Data Management and Analysis (18*)
2. Sustainability/ROI (16*)
3. Intelligent Compaction and In Situ Correlations (13*)
4. Education Program/Certification Program (11*)
5. In Situ Testing Advancements and New Mechanistic Based QC/QA (10*)
6. Intelligent Compaction Specifications/Guidance (6*)
7. Project Scale Demonstration and Case Histories (3*)
8. Standardization of Roller Outputs and Format Files (3*)
9. Understanding Impact of Non-Uniformity of Performance (2*)
10. Standardization of Roller Sensor Calibration Protocols (1*)
11. Intelligent Compaction Technology Advancements and Innovations (1*)
12. Understanding Roller Measurement Influence Depth (0*)
13. Intelligent Compaction Research Database (0*)

*total votes are provided in parenthesis

Introduction

Technology Transfer Intelligent Compaction Consortium (TTICC)

Increasingly, state departments of transportation (DOTs) are challenged to design and build longer life pavements and infrastructure that result in a higher level of user satisfaction for the public. One of the strategies for achieving longer life pavements is to use innovative technologies and practices. In order to foster new technologies and practices, experts from state DOTs, the Federal Highway Administration (FHWA), academia, and industry must collaborate to identify and examine new and emerging technologies and systems. As a part of this effort, the Iowa DOT and the Center for Earthworks Engineering Research (CEER) hosted three workshops on Intelligent Compaction for Soils and Hot Mix Asphalt (HMA) since 2008 and developed a roadmap to address the research, implementation, and educational needs to integrate intelligent compaction (IC) into practice. Realizing that a national forum is needed to provide broad leadership that can rapidly address the needs and challenges facing DOTs with the adoption of IC technologies, the Iowa DOT initiated the TTICC project under the Transportation Pooled Fund Program (TPF Study Number 5(233)). The purpose of this pooled fund project is to identify, support, facilitate, and fund IC research and technology transfer initiatives. At this time, the following state highway agencies are part of this pooled fund study: California DOT, Georgia DOT, Iowa DOT, Kentucky DOT, Missouri DOT, Ohio DOT, Pennsylvania DOT, Virginia DOT, and Wisconsin DOT (Figure 1).

The goals of the TTICC are as follows:

- Identify needed research projects
- Develop pooled fund initiatives
- Plan and conduct an annual workshop on intelligent compaction for soils and asphalt
- Provide a forum for technology exchange between participants
- Develop and fund technology transfer materials
- Provide on-going communication of research needs faced by state agencies to the FHWA, states, industry, and the CEER

This report presents the details and summary of findings from the 4th TTICC Workshop held on October 27–28, 2015 in Frankfort, Kentucky. The workshop was attended by sixteen representatives from state DOTs, two representatives from the FHWA, two representatives each from Iowa State University and University of Kentucky, and one representative from industry (Plantmix Asphalt Industry of Kentucky). A picture of the participants on Day 2 is provided in Figure 2.

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[1]White D.J., (2008). *Report of the Workshop on Intelligent Compaction for Soils and HMA.* ER08-01, Workshop Organized by the Earthworks Engineering Research Center at Iowa State University and the Iowa Department of Transportation, April 2–4, West Des Moines, Iowa.

[2]White D.J., and Vennapusa, P. (2009). *Report of the Workshop on Intelligent Construction for Earthworks.* ER09-02, Workshop Organized by the Earthworks Engineering Research Center at Iowa State University and the Iowa Department of Transportation, April 14–16, West Des Moines, Iowa.

[3]White, D.J., and Vennapusa, P. (2010). *Report of the Webinar Workshop on Intelligent Compaction for Earthworks and HMA.* ER10-02, Workshop Organized by the Earthworks Engineering Research Center at Iowa State University and the Iowa Department of Transportation, March 1–2.

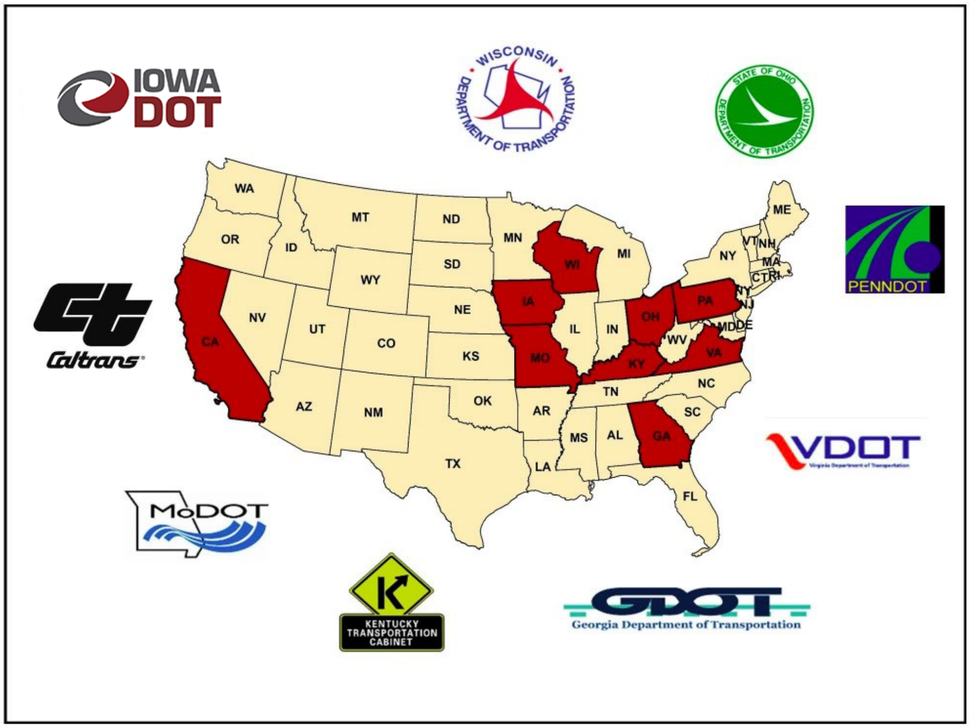

Figure 1. TTICC pooled fund study participating states (highlighted in red) as of 2015

Figure 2. Picture showing TTICC participants on Day 2

Workshop Objectives and Agenda

The following were the key objectives of this workshop:

- Review and exchange experiences of state DOTs in implementing IC for earthwork and HMA
- Review the existing IC specifications
- Facilitate a collaborative exchange of information between state DOTs, the FHWA, and industry to accelerate effective implementation of IC technologies
- Update the IC roadmap for identifying key research/implementation/education needs, and action items for the TTICC group, the FHWA, and industry

The workshop was held over two days. The workshop events involved introductions with a brief review of each participant's technical focus and job responsibilities; overview of the TTICC project goals, objectives, and deliverables; state DOT briefings for IC projects and implementation; discussions on the recent IC specifications and challenges associated with implementation of those specifications; reprioritizing IC research, implementation, and educational needs; and defining the TTICC goals for 2016.

Updates by CEER, state DOT briefings for IC projects and implementation, general discussions, prioritized IC implementation road map, and proposed action items for the TTICC, the FHWA, and industry to advance IC research and implementation are presented in the following sections of this report.

The complete workshop agenda is included in Appendix A, and a list of attendees is provided in Appendix B. A copy of all workshop presentations and products provided to the participants is provided in Appendices C and D, respectively. Comments evaluating the workshop are included in Appendix E.

TTICC Update by CEER

A presentation was made summarizing background information on IC for soils and HMA and the TTICC efforts. Presentation slides are provided in Appendix C. A log of discussion points during the presentation are as follows:

Slide 11 [Comment by Daniel Clark, Penn DOT]: It would be good to know how tire influence depth compares with roller influence depth on Slide 11 of the presentation.

Slide 13 [Comment by Daniel Clark, Penn DOT]: How can one settle on the color scale?

> **Response by David White:** The color scale should be adjusted based on field calibration. It can be simplified to more of a pass/fail map [two colors] if the data is calibrated.

Slide 13 [Comment by Daniel Clark, Penn DOT]: There are many relatively small areas that show low values. How can we definitely say the area is statistically different that areas around it?

> **Response by David White:** This is an important issue to address. There are data analytic methods to define this and must be integrated into the display so decisions can be made on site. We are currently working on this.

Slide 16 [Comment by Ian Rish, Georgia DOT]: Doing field correlations is tough. We have a lot of data with density, but it has poor R^2 values.

State DOT Briefings for IC Projects and Implementation

The following is a log of state DOT briefings for IC projects and implementation during the day one sessions.

Georgia DOT: Used on Brunswick project on subgrade and base. Compaction meter values did not work properly on the subgrade, so the contractor used machine drive power (MDP) because it could be used in static mode. Contractor rented the equipment. The project is completed. No correlation was found with nuclear gauge density. Also used on another project in the north part of the state. The project consisted of micaceous soils. Contractor used MDP with static compaction. Contractor bought the equipment. Again, correlation with nuclear gauge density was poor. Would have been great to have a dynamic cone penetrometer (DCP) on site. Georgia DOT has been considering performance specifications. Using Veta has been challenging. Trimble's VisionLink software was relatively easy to use. Post-processing the data is still very challenging.

Missouri DOT (Bill Stone): As indicated during last year's meeting in early 2014, Missouri DOT did a proof of concept with pass count and coverage only on HMA. Used Hamm and Caterpillar rollers. Goal was to expose contractor to IC. Contractor rented the rollers. Data imported to Veta. Data filtering and processing became challenging with data from multiple rollers. We did a blind study for two days and then used IC on the remaining days. VisionLink was used to get data from rollers. NOBA IR scanner was used for one week. This project was done as proof-of-concept with temperature and roller passes only, no stiffness measurements were used. One more project was planned in a rural area, but had poor GPS coverage. In 2015 we started using IR technology for HMA. We formed an IC specification team at Missouri DOT. Draft performance specifications for HMA has been developed and working on soils and embankment as part of the SHRP R07. Need to get a request for proposal out to develop a specification probably by end of the year.

Missouri DOT (Kevin McClain): Finishing a study on evaluating alternatives for nuclear gauge. Evaluated nine different test devices. Worked on several active project sites—mostly small sites. Looked at operating costs for nuclear gauge versus others. We also evaluated DCP and light weight deflectometer (LWD) tests by going through chiropractor services—looking on fatigue on field personnel. DCP is found to be a great tool to figure out how much material need to be excavated. Prices are dropping on LWD. A combination of LWD and DCP is a good idea moving forward. Moisture testing using a microwave was evaluated. Not interested in time-domain reflectometer devices. Currently working on papers and will make it available to all when ready.

Ohio DOT: Ohio DOT has been in standby mode for HMA as the results are influenced by the underlying layer. For earthwork we conducted two demo projects two years ago. We had similar problems with correlations as others reported—poor R^2 values with density and LWD modulus as well sometimes. The contractor who did the demo used IC rollers on shale gas projects and also used it on a public-private partnership 70-mile-long project on some portions.

Iowa DOT: Iowa DOT has not done any new implementation projects since 2014. We have used it on the Highway 65 project as discussed by Dave White in the presentation. Contractor provided positive feedback. Iowa DOT is looking into whether or not to participate in the Veta pooled fund study initiated by Minnesota DOT.

Pennsylvania DOT: See presentation slides in Appendix C. Average cost of using IC was about $0.15/yd². There were some issues with GPS signal on roads with trees and stray electrical signal (overhead electrical wires). We are trying to prepare a new specification by the end of the year. We did monitor temperature, but not sure how it helped. There were software issues with Veta. There are not enough people in the DOT to handle the data and keep up with the software updates. Biggest issue was that old version (version 2) files were not compatible with the new version (version 3). Pennsylvania DOT spent nearly $1 million on using IC on projects, cannot define what the return on investment is. Pennsylvania DOT is organizing a conference call with Volvo on their new technology. If anyone is interested, they can join the call.

Comment from the FHWA: We are also having same problem with explaining return on investment and we are working on it.

KYTC: See presentation slides in Appendix C. Kentucky DOT is planning on using IC on an asphalt overlay over bridge. University of Kentucky is working on a research project to gather data. IC specifications were written for an embankment subgrade/base/HMA paving project. 80% coverage requirement was specified. We are still using nuclear gauge for QA on soils and cores for QA on HMA. Not sure how we address the correlations issue.

Virginia DOT: There is a lot of reluctance in the upper management at the Virginia DOT. Also many contractors are not ready for implementation. Many small issues to resolve, as everybody discussed, but these are becoming major hindrances for implementation.

FHWA: EDC-2 initiative included IC. Many states are now using the FHWA guide specifications to develop their specifications. There are two new "roadeos" coming up—one in California on HMA and one in Texas on soils. University of Texas at El Paso is conducting research for project in Texas. Veta new version is in development as part of the two-year pooled fund study. Trying to resolve many of the issues discussed today. Most big contractors are okay to use IC since it is only for QC now. Small contractors are very reluctant because of the capital cost.

General Discussion and Updated IC Implementation Road Map and Action Items for TTICC, FHWA, and Industry

The TTICC group voted on the IC technology research/implementation needs identified in the 3rd workshop report. Each group member was given seven votes. The prioritized list of IC technology research/implementation needs is presented in Table 1. Table 2 presents the change in the ratings of different roadmap elements since 2008, highlighting the transitions of top-rated elements. The *intelligent compaction specifications* and *in situ correlations* road map elements have remained in the top two between 2009 and 2011. The *data management* road map element was rated as the top one since 2012, including this year.

Progress with pilot IC specifications recently implemented by the DOTs and firsthand experience on challenges associated with real-time data transfer and analysis has shaped the prioritized rankings. The *sustainability/return of investment* element moved from rank 4 (in 2014) to rank 2 this year as a result of many participants feeling the importance of characterizing the economic advantage associated with using IC both during construction and in long-term because of potentially improved performance. This has been viewed by the participants as one of the major roadblocks in convincing the contractor, senior management, and DOT to implement IC.

The revised roadmap elements are presented in Table 3. After reviewing the revised road map, discussion focused on defining action items needed to advance for each element. The outcome was to identify not only needed action items, but linking the action items to the TTICC, the FHWA, and industry. Table 4 presents the action items identified for the TTTIC group, the FHWA, and industry on each of the roadmap elements.

The *data management* element was discussed further by the team (per notes from Figure 3) and the following were identified as key elements that IC data analytics software should include:

1. Link to user need (inspector, contractor, or engineer). This will define the type and level of analysis tools.
2. Provide guidance on how to set scales—relate to target values based on on-site calibration. Three color scale (Good, Marginal, Bad).
3. Built-in calibration data analysis capability including proper statistical analysis.
4. Link results to ArcGIS collector (mobile device) or something simpler to be able to collect and enter data in an easy way.
5. Conduct project scale as well as lot scale analysis. Current IR scanner uses 150 ft for lot scale analysis.
6. Link to Soil ID through asset management data.
7. Link to design, and QC/QA data.
8. Show "area of interest" based on the IC measurement values. The area should of high statistical significance for additional work. Also, provide guidance on action plan (rework or additional compaction or dry, etc.).

9. Random sampling for QA—need a test point locator that can provide a truly random sample and provide needed documentation.
10. Incorporate ability to determine lot boundaries on the "fly" so the QA test locations are truly random.
11. Incorporate ability to calculate real-time unit quantities.

During the workshop meeting the IC workflow process was discussed and it was decided that it would be helpful to establish a list of the key workflow processes. By better understanding the many decisions and groups within the DOT, agencies need to provide input to the workflow; improved and more effective outcomes are expected. Figure 4 illustrates a preliminary workflow process for integrating IC into projects. The intent of the preliminary workflow is to organize discussion moving forward such that each agency can develop customized workflow processes that meet their internal needs. A key elements of the workflow is the ability to communicate various input needs through the process of selecting IC for projects and developing effective specification requirements.

Table 1. Prioritized IC technology research/implementation needs – 2015 TTICC workshop

Prioritized IC/CCC Technology Research/Implementation Needs

1. **Data Management and Analysis (18*)**
2. **Sustainability/ROI (16*)**
3. **Intelligent Compaction and In Situ Correlations (13*)**
4. **Education Program/Certification Program (11*)**
5. **In Situ Testing Advancements and New Mechanistic Based QC/QA (10*)**
6. **Intelligent Compaction Specifications/Guidance (6*)**
7. **Project Scale Demonstration and Case Histories (3*)**
8. **Standardization of Roller Outputs and Format Files (3*)**
9. **Understanding Impact of Non-Uniformity of Performance (2*)**
10. **Standardization of Roller Sensor Calibration Protocols (1*)**
11. **Intelligent Compaction Technology Advancements and Innovations (1*)**
12. **Understanding Roller Measurement Influence Depth (0*)**
13. **Intelligent Compaction Research Database (0*)**

*total votes are provided in parenthesis

Table 2. IC/CCC research, implementation, and educational elements, ratings from 2008 to 2015

Rating	2008[1]	2009[2]	2010[3]	2011[4]	2012	2014	2015
1	Correlations	Specifications	Correlations	Correlations	Data Management	Data Management	Data Management
2	Education	Correlations	Specifications	Specifications	Specifications	Education	Sustainability/ ROI
3	Moisture Content Influence	Mechanistic QC/QA	Mechanistic QC/QA	Data Management	Correlations	Correlations	Correlations
4	Data Management	Non-Uniformity	IC Advancements	Demo Projects	Non-Uniformity	Sustainability/ ROI	Education
5	Demo Projects	Data Management	Demo Projects	Education	Output Standardization	Specifications	Mechanistic QC/QA
6	Mechanistic QC/QA	Demo Projects	Non-Uniformity	Non-Uniformity	Sensor Calibration	Non-Uniformity	Specifications
7	Non-Uniformity	Influence Depth	Data Management	Output Standardization	Education	Mechanistic QC/QA	Demo Projects
8	Specifications	IC Advancements	Output Standardization	Database	Influence Depth	Influence Depth	Output Standardization
9	Influence Depth	Education	Influence Depth	Mechanistic QC/QA	Demo Projects	Sensor Calibration	Non-Uniformity
10	Promoting Best Practices	Database	Education	Influence Depth	Mechanistic QC/QA	IC Advancements	Sensor Calibration
11	—	—	Database	IC Advancements	IC Advancements	Database	IC Advancements
12	—	—	Sensor Calibration	Sustainability	Database	Demo Projects	Influence Depth
13	—	—	—	Sensor Calibration	Sustainability	Output Standardization	Database

Table 3. Revised IC road map research, implementation, and educational elements – 4th TTICC workshop

IC Road Map Research, Implementation, and Educational Elements

1. **Data Management and Analysis [1*]. The data generated from IC compaction operations is 100+ times more than traditional compaction QC/QA operations and presents new challenges. The research element should focus on data analysis, visualization, and management, and be based on a statistically reliable framework that provides useful information to assist with the construction process control. This research element is cross cutting with elements 2, 3, 5, 7, 8, 11, and 12.**

2. **Sustainability/Return of Investment [4*]. This research element involves evaluating benefits of IC in terms of sustainability aspects such as the potential for use of less fuel during construction, reduced life-cycle and infrastructure maintenance costs, etc.**

3. **Intelligent Compaction and In Situ Correlations [3*]. This research element will develop field investigation protocols for conducting detailed correlation studies between IC measurement values and various in situ testing techniques for earth materials and HMA. Standard protocols will ensure complete and reliable data collection and analysis. Machine operations (speed, frequency, vibration amplitude) and detailed measurements of ground conditions will be required for a wide range of conditions. Relationships between HMA and WMA mix temperature, roller measurement values, and performance should be developed. A comprehensive research database and methods for establishing IC target values will be the outcome of this study. Information generated from this research element will contribute to elements 2, 7, 8, 10, and 12. There is a need to define gold standard QC/QA in situ test measurement for correlations depending on the material type (i.e., soils, base, or asphalt).**

4. **Education Program/Certification Programs [2*]. This educational element will be the driver behind IC technology and specification implementation. Materials generated for this element should include a broadly accepted and integrated certification program that can be delivered through short courses and via the web for rapid training needs. Operator/inspector guidebook and troubleshooting manuals should be developed. The educational programs need to provide clear and concise information to contractors and state DOT field personnel and engineers. A potential outcome of this element would be materials for National Highway Institute training courses.**

5. **In Situ Testing Advancements and New Mechanistic Based QC/QA [7*]. This research element will result in new in situ testing equipment and testing plans that target measurement of performance-related parameter values including strength and modulus. This approach lays the groundwork for better understanding the relationships between the characteristics of the geo-materials used in construction and the long-term performance of the system.**

6. **Intelligent Compaction Specifications/Guidance [5*]. This research element will result in several specifications encompassing method, end-result, performance-related, and performance-based options. This work should build on the work conducted by various state DOTs, NCHRP 21-09, and the ongoing FHWA IC Pooled Fund Study 954. The new specifications should be technology independent and should allow use of different QC/QA testing devices and IC measurement values. This research element is crosscutting with elements 3, 5, 6, 7, and 8.**

7. **Project Scale Demonstration and Case Histories [12*]. The product from this research element will be documented experiences and results from selected project-level case histories for a range of materials, site conditions, and locations across the United States. Input from contractor and state agencies should further address implementation strategies and needed educational/technology transfer needs. Conclusive results with respect to benefits of IC technology should be reported and analyzed. Information from this research element will be integrated into elements 1, 2, 4, and 7.**

*1st TTICC workshop rating.

Table 3. Revised IC road map research, implementation, and educational elements, 4th TTICC workshop

8. **Standardization of Roller Outputs and Format Files [13*]. This research element involves developing a standardized format for roller output and format files. This element crosscuts with specification element 2.**

9. **Understanding Impact of Non-Uniformity on Performance [6*]. This track will investigate relationships between compaction non-uniformity and performance/service life of infrastructure systems—specifically pavement systems. Design of pavements is primarily based on average values, whereas failure conditions are affected by extreme values and spatial variations. The results of the research element should be linked to m input parameters. Much needs to be learned about spatial variability for earth materials and HMA and the impact on system performance. This element is crosscutting with elements 1, 2, and 7.**

10. **Standardization of Roller Sensor Calibration Protocols [8*]. IC rollers are equipped with measurement sensors (e.g., accelerometers in the case of vibratory-based technologies), GPS, data logging systems, and many onboard electronics. These sensors and electronics need periodic maintenance and calibration to ensure good repeatability in the measurement systems. This research element will involve developing a highly mobile mechanical system that could simulate a range of soil conditions and be deployed to a project site to periodically verify the roller output values. Further, establishment of a localized calibration center (similar to a falling weight deflectometer calibration center) by a state agency can help state agencies periodically verify the repeatability and reproducibility of the measurements from their sensors and other electronics.**

11. **Intelligent Compaction Technology Advancements and Innovations [10*]. Potential outcomes of this research element include development of improved IC measurement systems, addition of new sensor systems such as moisture content and mat core temperature, new onboard data analysis and visualization tools, and integrated wireless data transfer and archival analysis. Further, this research element will also explore retrofitting capabilities of IC measurement systems on existing rollers. It is envisioned that much of this research will be incremental and several sub-elements will need to be developed.**

12. **Understanding Roller Measurement Influence Depth [9*]. Potential products of this research element include improved understanding of roller operations, roller selection, interpretation of roller measurement values, better field compaction problem diagnostics, selection of in situ QA testing methods, and development of analytical models that relate to mechanistic performance parameter values. This element represents a major hurdle for linking IC measurement values to traditional in situ test measurements.**

13. **Intelligent Compaction Research Database [11*]. This research element would define IC project database input parameters and generate web-based input protocols with common format and data mining capabilities. This element creates the vehicle for state DOTs to input and share data and an archival element. In addition to data management/sharing, results should provide an option for assessment of effectiveness of project results. Over the long-term the database should be supplemented with pavement performance information. It is important for the contractor and state agencies to have standard guidelines and a single source for the most recent information. Information generated from this element will contribute to elements 2, 3, 7, 9, and 10.**

*3rd TTICC workshop (2012) rating.

Table 4. Updated action items for the TTICC project team, the FHWA, and industry

List of Action Items	TTICC	FHWA	Industry
1. Data Management and Analysis			
a. Define requirements (how to deal with legal issues in data sharing, and how to archive data)	x[1]		
b. Discuss with other state DOTs	x		
c. Enhance Capabilities of Software		x	x
d. Need Real Time Data Processing/Delivery Capabilities		x	x
e. Identify Future Use Needs for Data	x	x	
4. Sustainability/Return of Investment (ROI)			
a. Develop a Green Value Proposition	x		
b. Cost Information (Capital and Life-Cycle)	x[2]	x[2]	
c. Improvement in Safety	x	x	
3. IC and In Situ Correlations			
a. Develop a Standard Calibration Procedure and Best Practices Document	x[3]		
b. Problem Statement to Better Assess Influence of Moisture Content	x		
d. Support Research Efforts		x	

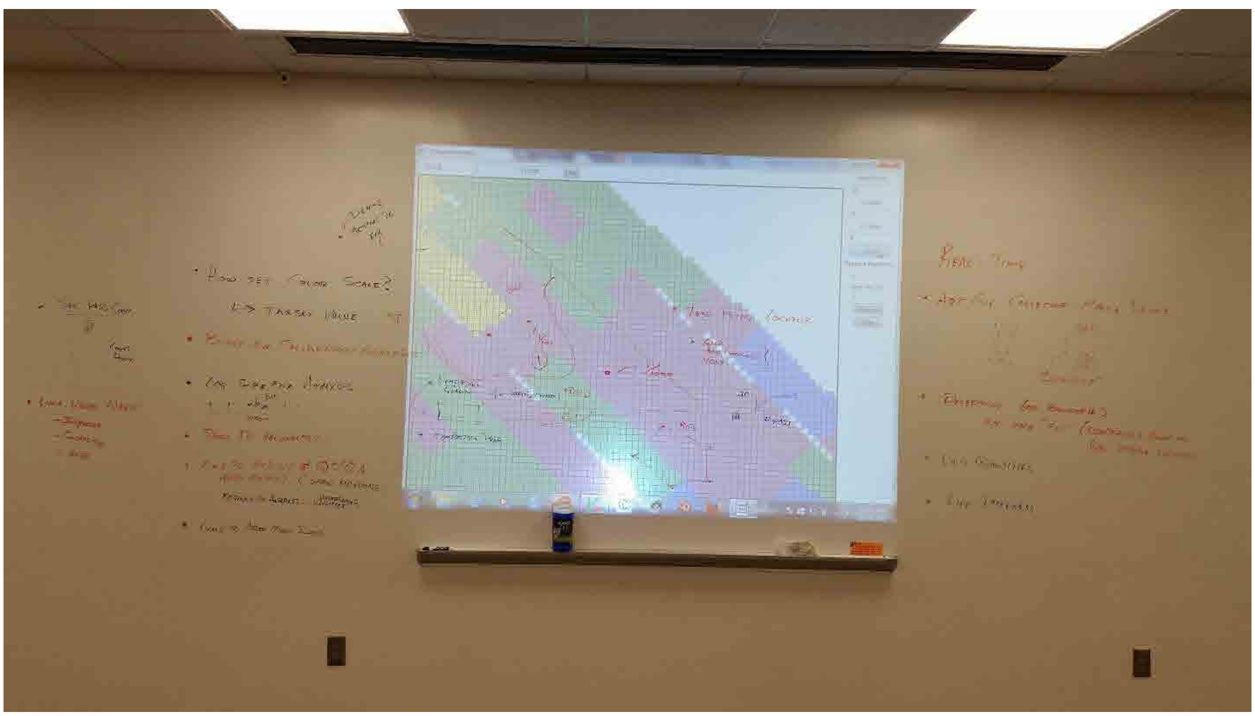

Figure 3. Picture showing TTICC participants identifying future data analytics needs as part of data management

[1]Identify GIS data archival protocal (one page)

[2]Need to get cost information for rolling operations (fuel and personnel time) with and without IC

[3]NCHRP synthesis on existing correlations

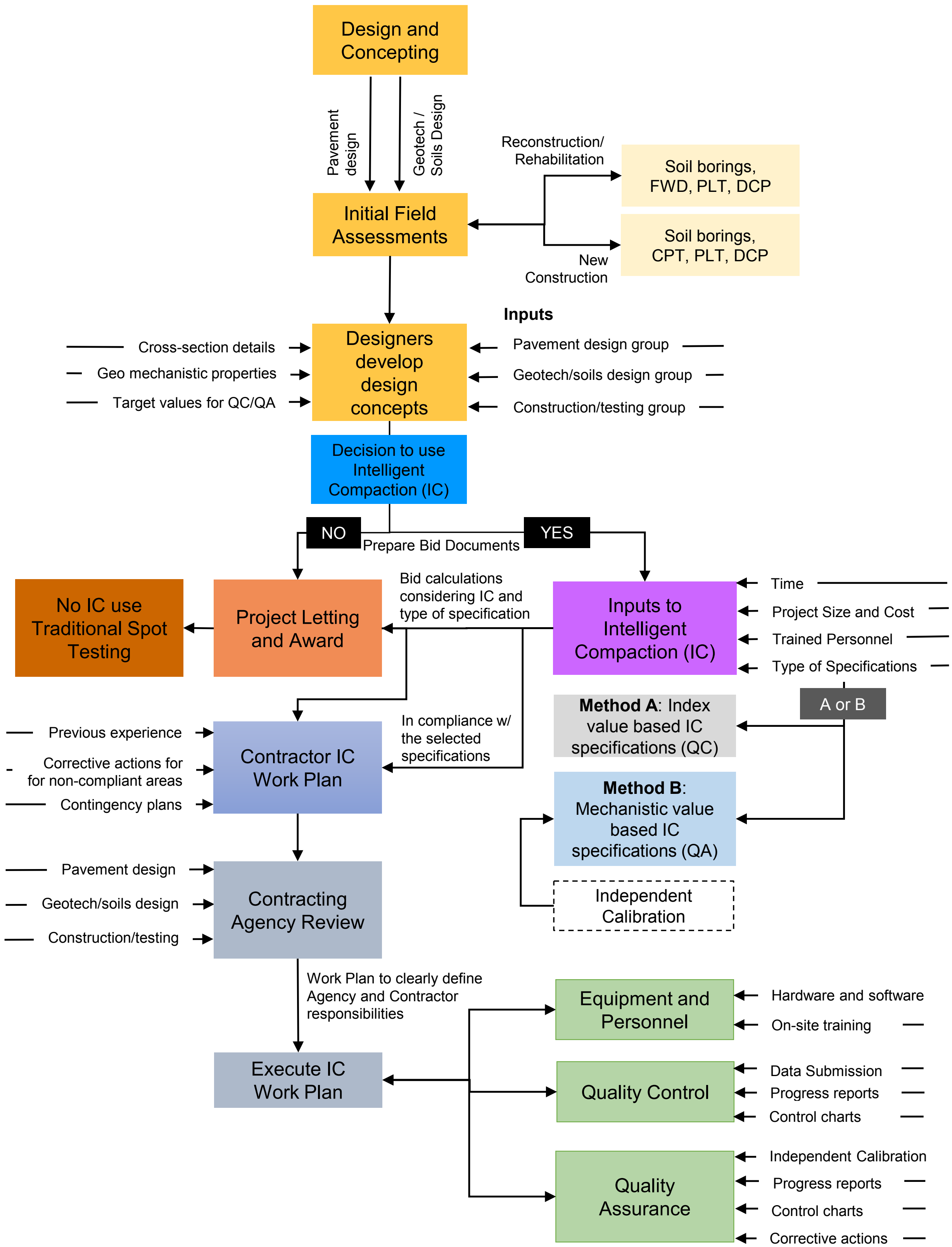

Figure 4. Preliminary IC workflow processes

Summary of Key Outcomes

Some of the key outcomes from this workshop were as follows:

1. Served as a forum for discussion between state DOTs, the FHWA, and industry representatives in addressing the challenges in implementing the IC technology.
2. Updated and prioritized the IC technology research, implementation, and educational needs road map.
3. Developed list of action items for the TTICC group, the FHWA, and industry to advance and accelerate implementation of IC technology into earthwork and asphalt construction practice.
4. Developed a preliminary IC workflow process that links design, construction, and testing phases.

Appendices

Appendix A: Workshop Agenda

Tuesday, October 27 — Room C107

8:00 am	Coffee and continental breakfast available
8:30 am	Introductions
9:00 am	TTICC update by CEER (tech transfer, upcoming IC opportunities, etc.)
9:30 am	State DOT IC implementation updates (CA, GA, IA, KY, MO, OH, PA, VA, and the FHWA)
10:00 am	**Morning break**
10:15 am	State DOT IC implementation updates (continued)
10:45 am	Kentucky IC experience and showcase projects(s)
12:00 pm	**Lunch**
1:00 pm	Working session to comment on existing and alternative IC specification (HMA and grading)
3:00 pm	**Afternoon break**
3:15 pm	Working breakout discussions (continued)
4:30 pm	Wrap up
6:00 pm	**Informal dinner at a local restaurant**

Wednesday, October 28 — Room 512

8:00 am	Coffee and continental breakfast available
8:15 am	Working breakout sessions to identify and discuss: • Specifications • QC/QA problems, challenges, opportunities • Re-prioritize/add/delete IC/CCC technology research/implementation needs • TTICC goals and future needs
10:00 am	**Morning break**
10:15 am	Working session (continued)
11:00 am	Summary and direction forward
11:30 am	Wrap up

Appendix B: Workshop Attendees

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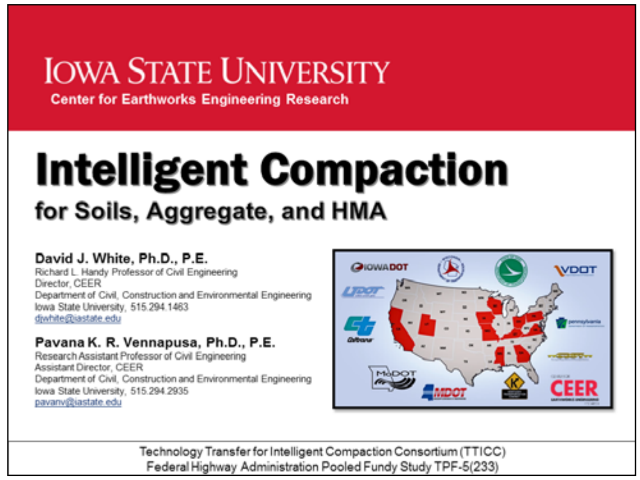
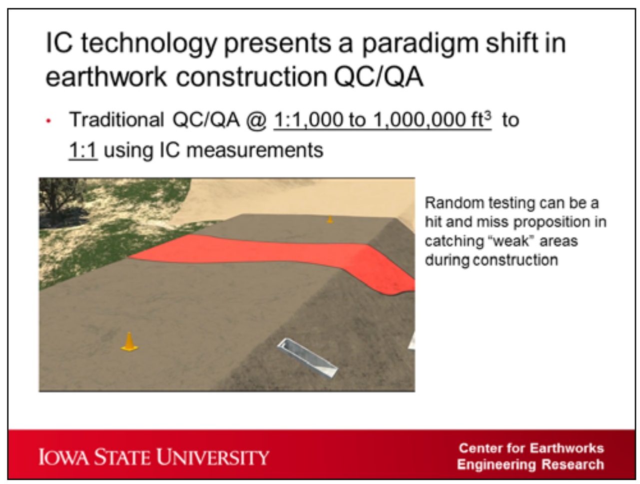
Appendix C: Workshop Presentations

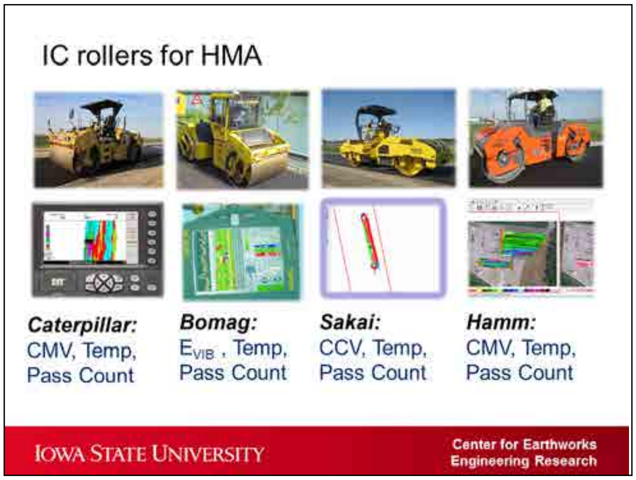
The following presentations were made at the workshop event and are provided herein in that order:

1. TTICC General Meeting Slides
2. History of IC in Kentucky
3. Asphalt Density Acceptance and Intelligent Compaction Field Trails (KYSPR 16-523)
4. Intelligent Compaction Update – Pennsylvania

TTICC General Meeting Slides







IC rollers for HMA
Caterpillar: CMV, Temp, Pass Count
Bomag: E_{VIB}, Temp, Pass Count
Sakai: CCV, Temp, Pass Count
Hamm: CMV, Temp, Pass Count
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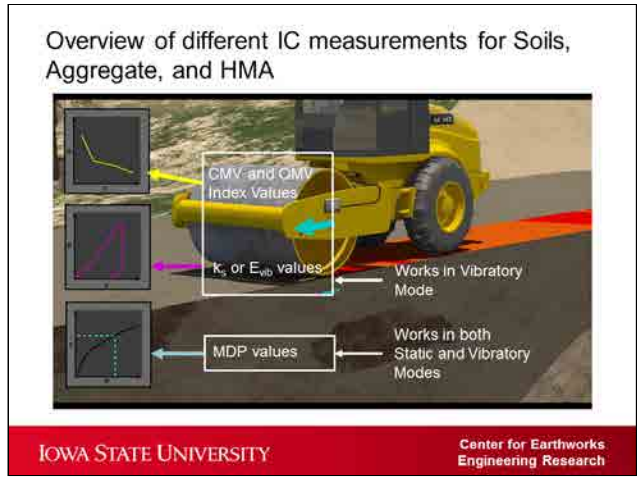

Overview of different IC measurements for Soils, Aggregate, and HMA
CMV and OMV Index Values
k_s or E_{vib} values
Works in Vibratory Mode
MDP values
Works in both Static and Vibratory Modes
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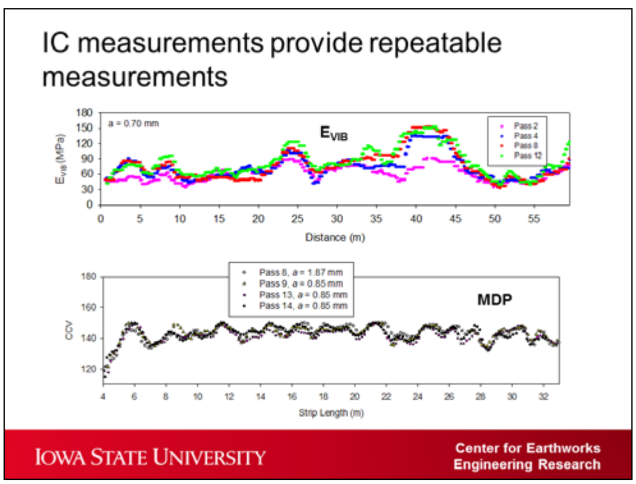

IC measurements provide repeatable measurements
a = 0.70 mm
E_{VIB}
Pass 2
Pass 4
Pass 8
Pass 12
E_{VIB} (MPa)
Distance (m)
Pass 8, a = 1.87 mm
Pass 9, a = 0.85 mm
Pass 13, a = 0.85 mm
Pass 14, a = 0.85 mm
MDP
CCV
Strip Length (m)
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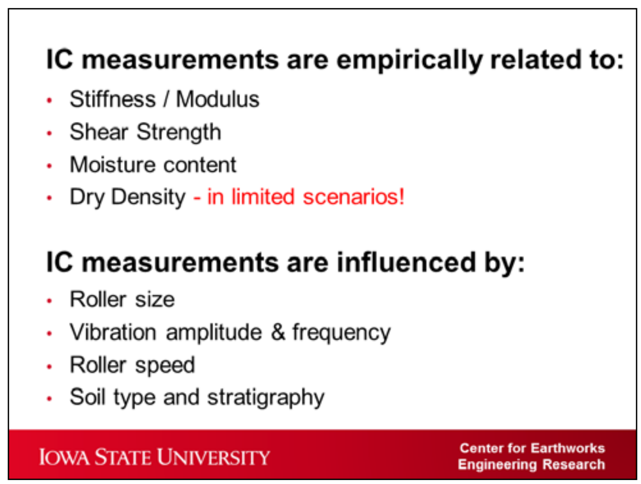

IC measurements are empirically related to:
Stiffness / Modulus
Shear Strength
Moisture content
Dry Density - in limited scenarios!
IC measurements are influenced by:
Roller size
Vibration amplitude & frequency
Roller speed
Soil type and stratigraphy
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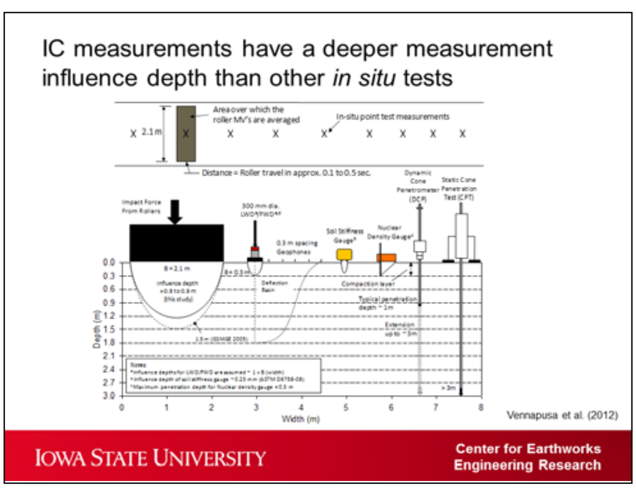

IC measurements have a deeper measurement influence depth than other in situ tests
Area over which the roller MV's are averaged
In-situ point test measurements
Distance = Roller travel in approx. 0.1 to 0.5 sec.
Impact Force From Rollers
Dynamic Cone Penetrometer (DCP)
Static Cone Penetration Test (CPT)
Soil Stiffness Gauge
Nuclear Density Gauge
Compaction layer
Depth (m)
Width (m)
Vennapusa et al. (2012)
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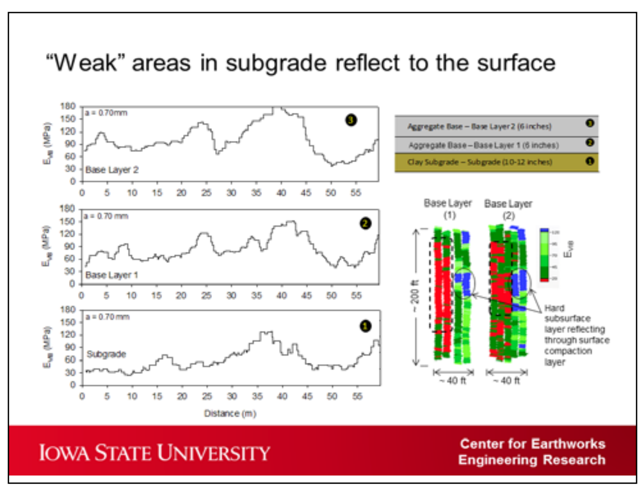

"Weak" areas in subgrade reflect to the surface
a = 0.70mm
Base Layer 2
Base Layer 1
Subgrade
E_{VIB} (MPa)
Distance (m)
Aggregate Base – Base Layer 2 (6 inches)
Aggregate Base – Base Layer 1 (6 inches)
Clay Subgrade – Subgrade (10-12 inches)
Base Layer (1)
Base Layer (2)
~ 200 ft
~ 40 ft
~ 40 ft
Hard subsurface layer reflecting through surface compaction layer
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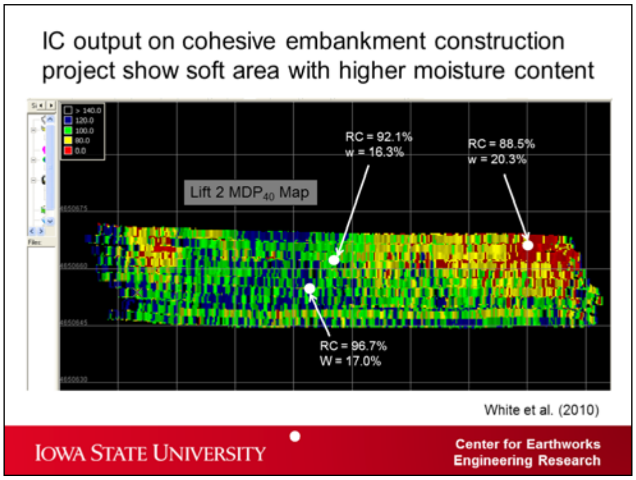
IC output on cohesive embankment construction project show soft area with higher moisture content
Lift 2 MDP_{40} Map
RC = 92.1%
w = 16.3%
RC = 88.5%
w = 20.3%
RC = 96.7%
W = 17.0%
White et al. (2010)
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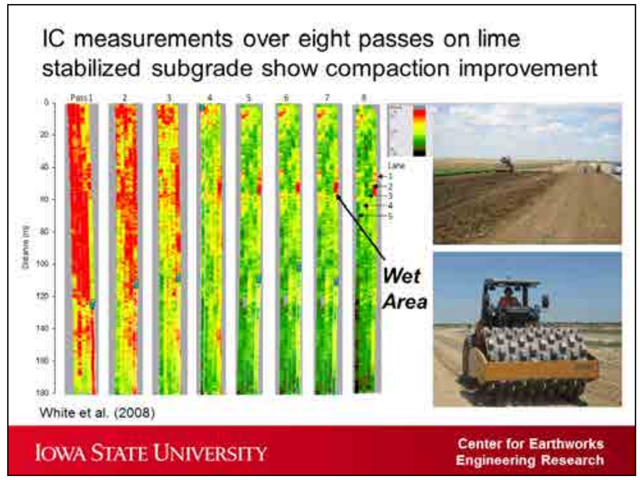
IC measurements over eight passes on lime stabilized subgrade show compaction improvement
Wet Area
White et al. (2008)
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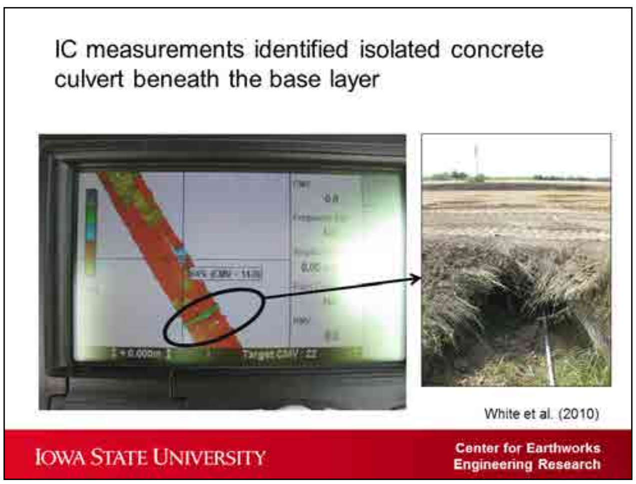
IC measurements identified isolated concrete culvert beneath the base layer
White et al. (2010)
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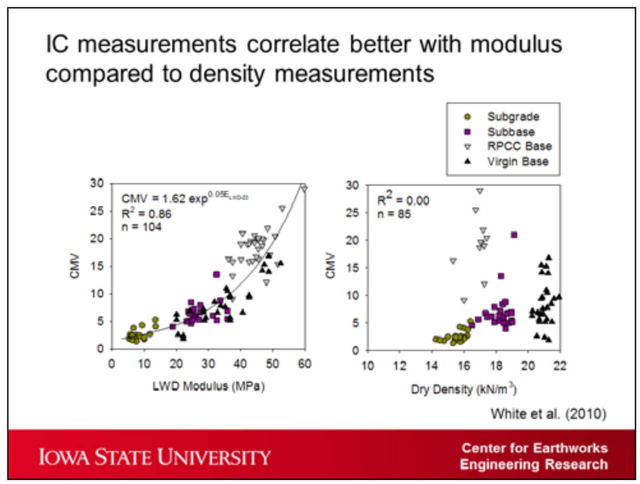
IC measurements correlate better with modulus compared to density measurements
Subgrade
Subbase
RPCC Base
Virgin Base
$R^2 = 0.86$
n = 104
$R^2 = 0.00$
n = 85
CMV
LWD Modulus (MPa)
Dry Density (kN/m^3)
White et al. (2010)
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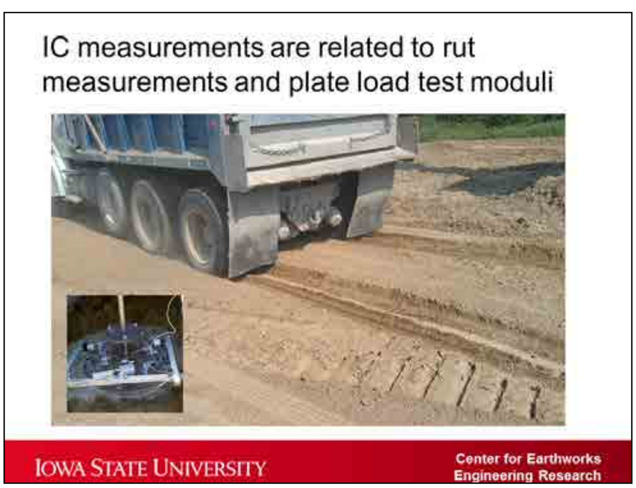
IC measurements are related to rut measurements and plate load test moduli
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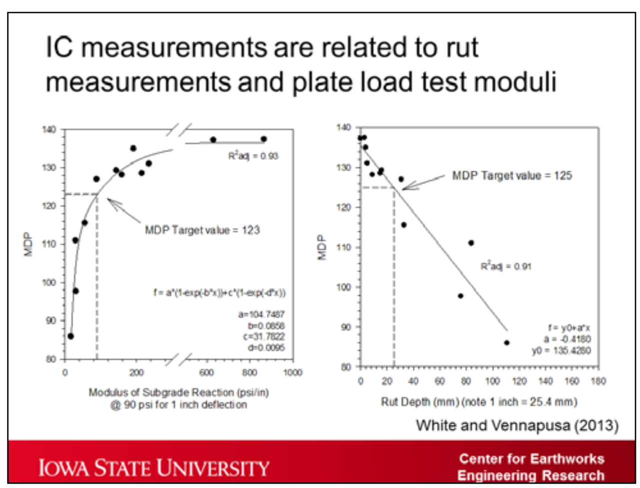
IC measurements are related to rut measurements and plate load test moduli
MDP Target value = 123
MDP Target value = 125
MDP
Modulus of Subgrade Reaction (psi/in) @ 90 psi for 1 inch deflection
Rut Depth (mm) (note 1 inch = 25.4 mm)
White and Vennapusa (2013)
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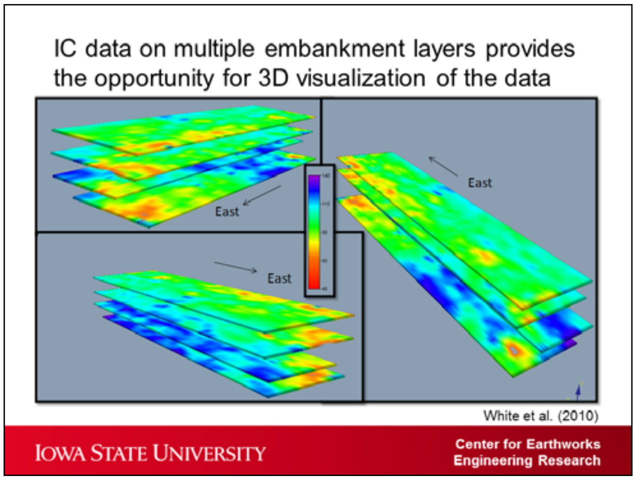
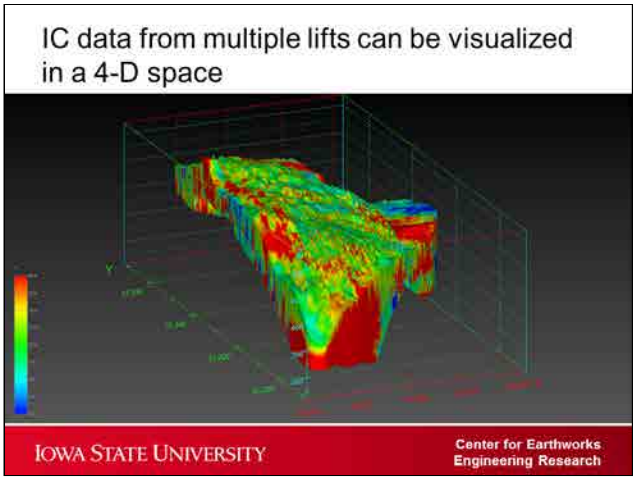
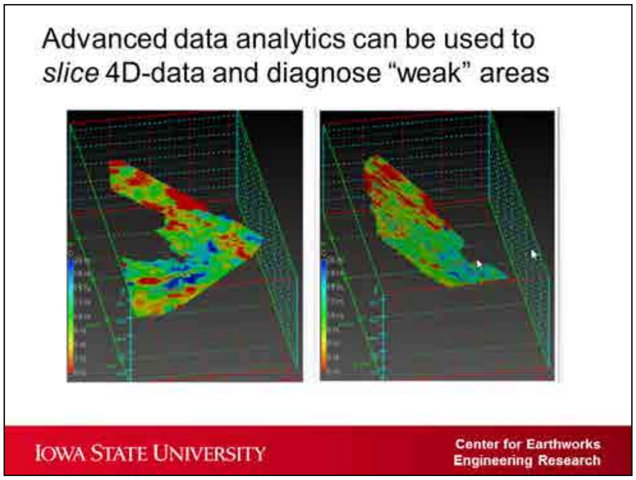
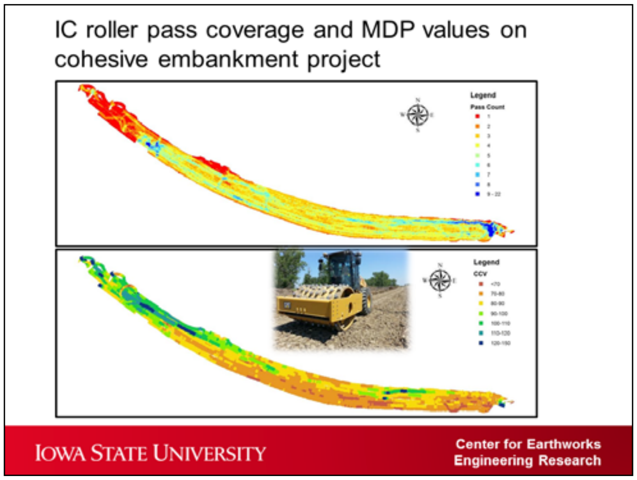
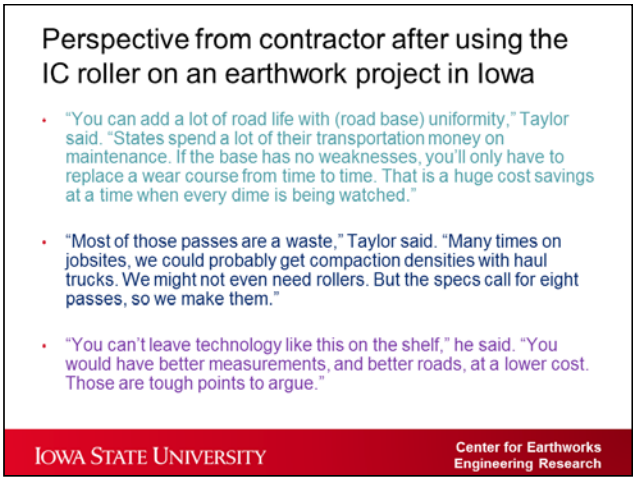
TTICC General Meeting Slides

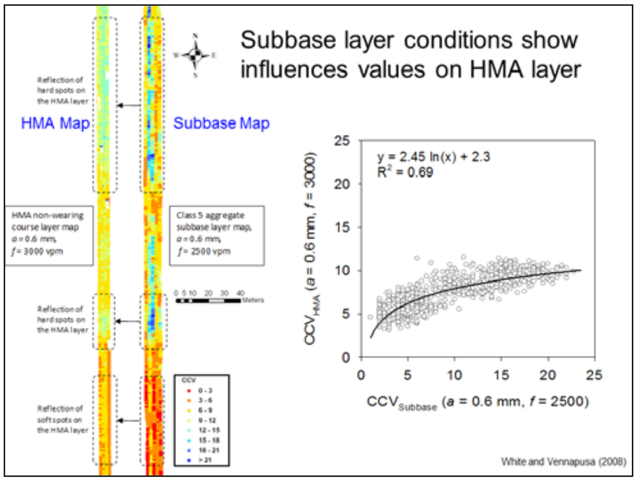


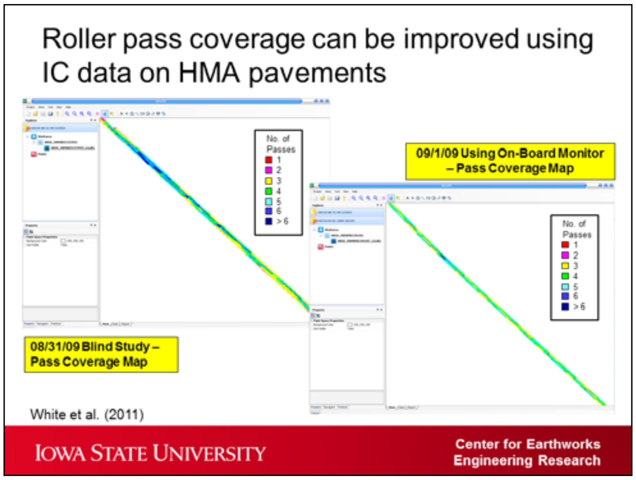


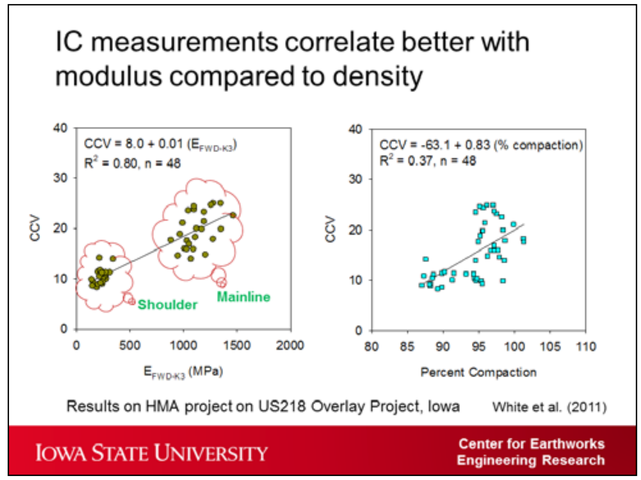


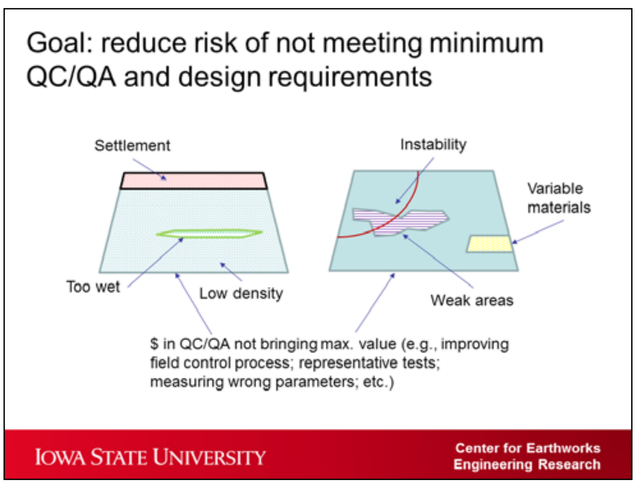


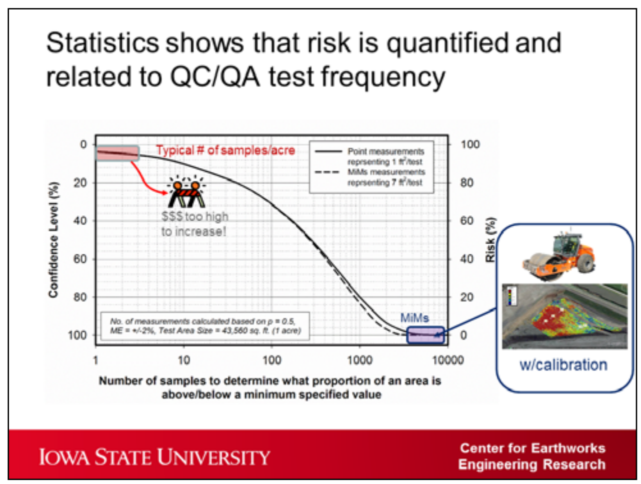


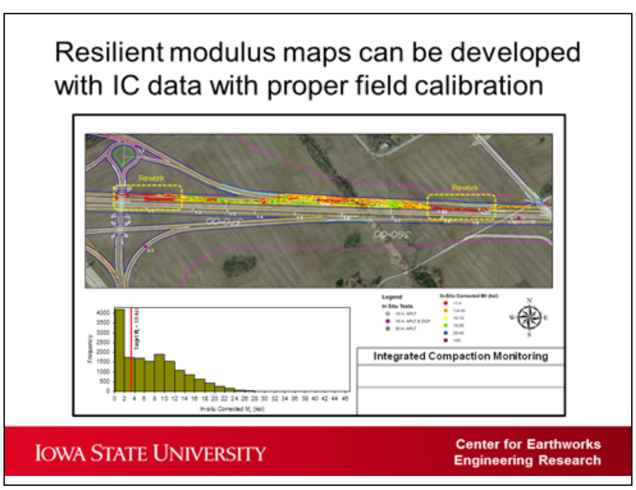


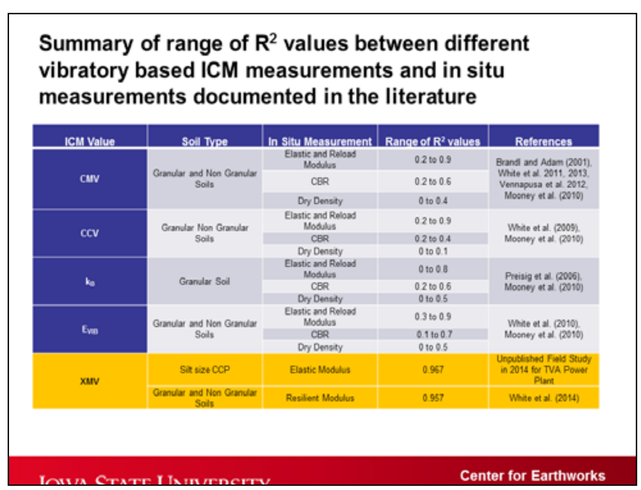




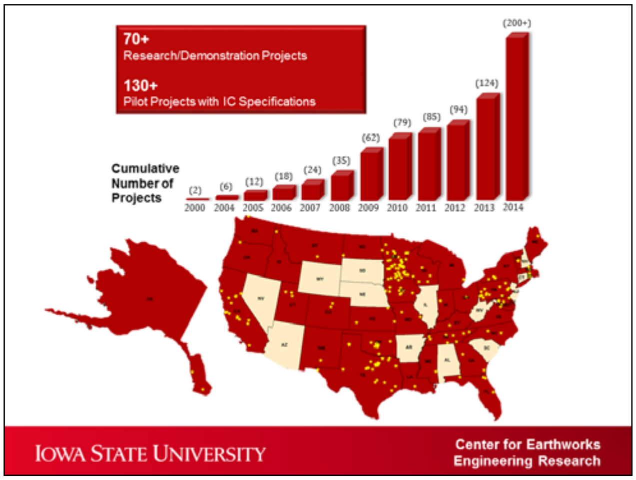








ICM Value	Soil Type	In Situ Measurement	Range of R^2 values	References
CMV	Granular and Non Granular Soils	Elastic and Reload Modulus	0.2 to 0.9	Brandl and Adam (2001), White et al. 2011, 2013, Vennapusa et al. 2012, Mooney et al. (2010)
		CBR	0.2 to 0.6	
		Dry Density	0 to 0.4	
CCV	Granular Non Granular Soils	Elastic and Reload Modulus	0.2 to 0.9	White et al. (2009), Mooney et al. (2010)
		CBR	0.2 to 0.4	
		Dry Density	0 to 0.1	
k_B	Granular Soil	Elastic and Reload Modulus	0 to 0.8	Preisig et al. (2006), Mooney et al. (2010)
		CBR	0.2 to 0.6	
		Dry Density	0 to 0.5	
E_{VIB}	Granular and Non Granular Soils	Elastic and Reload Modulus	0.3 to 0.9	White et al. (2010), Mooney et al. (2010)
		CBR	0.1 to 0.7	
		Dry Density	0 to 0.5	
XMV	Silt size CCP	Elastic Modulus	0.967	Unpublished Field Study in 2014 for TVA Power Plant
	Granular and Non Granular Soils	Resilient Modulus	0.957	White et al. (2014)


70+
Research/Demonstration Projects
130+
Pilot Projects with IC Specifications
Cumulative Number of Projects
(2) 2000
(6) 2004
(12) 2005
(18) 2006
(24) 2007
(35) 2008
(62) 2009
(79) 2010
(85) 2011
(94) 2012
(124) 2013
(200+) 2014
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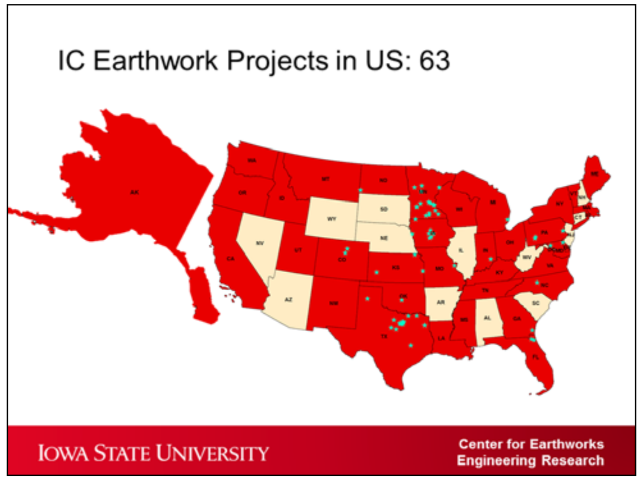
IC Earthwork Projects in US: 63
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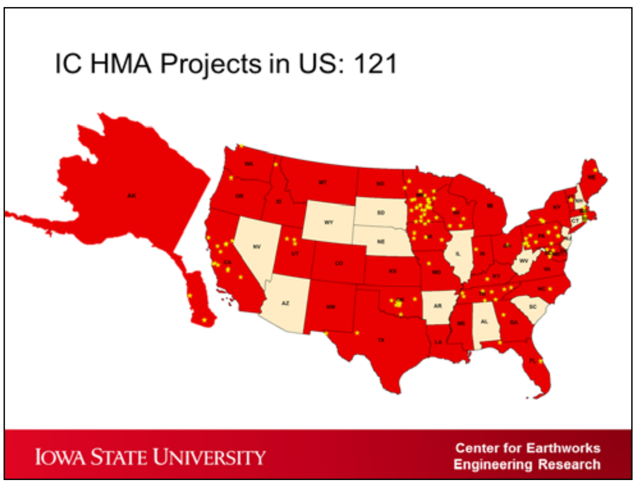
IC HMA Projects in US: 121
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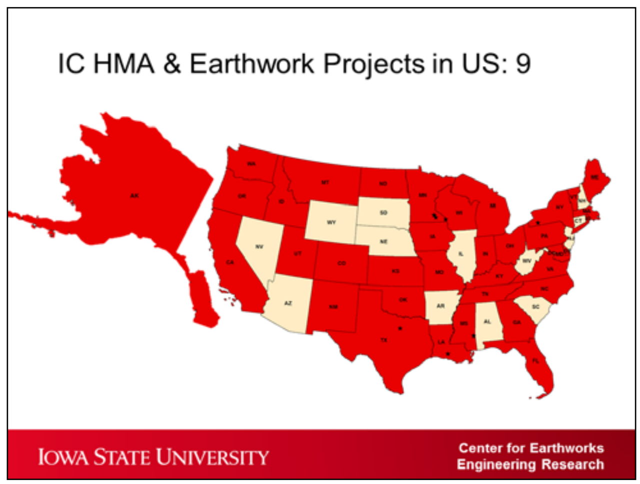
IC HMA & Earthwork Projects in US: 9
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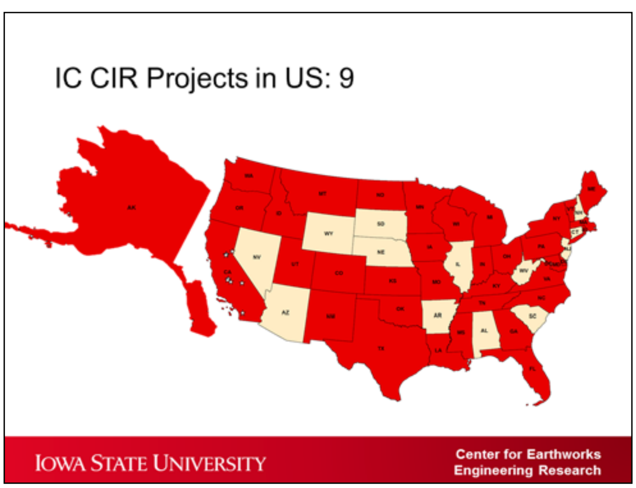
IC CIR Projects in US: 9
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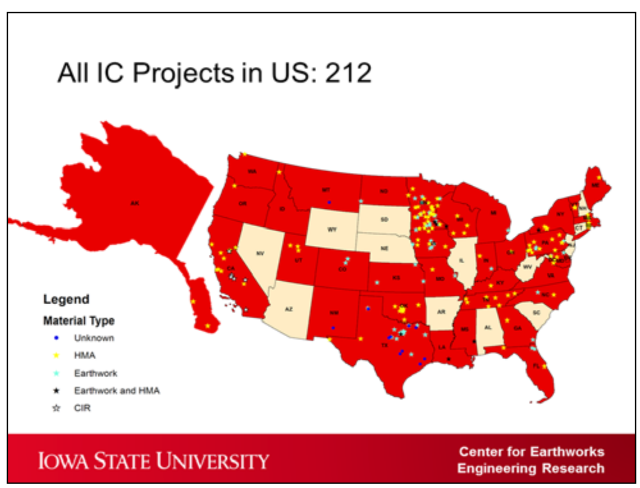
All IC Projects in US: 212
Legend
Material Type
Unknown
HMA
Earthwork
Earthwork and HMA
CIR
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Developed By	HMA (Year)	Soils (Year)
State Agency		
Alaska DOT	Yes (2014)	Yes (2015 Draft)
Arizona DOT	Yes (2014)	No
California DOT	Yes (2014) [Includes CIR]	No
Georgia DOT	Yes (2012)	Yes (2012)
Iowa DOT	Yes (2013)	Yes (2010)
Indiana DOT	Yes (2014)	No
Kentucky DOT	Yes (2015)	Yes (2015)
Massachusetts DOT	Yes (2013)	No
Michigan DOT	No	Yes (2013)
Minnesota DOT	Yes (2014)	Yes (2014)
Missouri DOT	No	Yes (2009)
North Carolina DOT	Yes (2013)	Yes (2012)
Nevada DOT	Yes (2013)	No
New Jersey DOT	Yes (2014)	No
New Mexico DOT	Yes (2014)	No
North Carolina DOT	Yes (2014)	Yes (2014)
Oklahoma DOT	Yes (2014)	No
Oregon DOT	Yes (2015)	No
Pennsylvania DOT	Yes (2014)	No
Rhode Island DOT	Yes (2013)	No
Tennessee DOT	Yes (2013)	No
Texas DOT	No	Yes (2013)
Utah DOT	Yes (2013)	No
Vermont DOT	Yes (?)	Yes (?)
Washington DC	Yes (2014)	Yes (2014)
Federal Agency		
AASHTO	Yes (2015)	Yes (2015)
Central Federal Land	Yes (2012)	No
Eastern Federal Land	Yes (2013)	
SHRP2 R07	No	Yes (2014)
FHWA (Generic Specs)	Yes (2014)	Yes (2014)

IC specifications for Soils and HMA in U.S.

Center for Earthworks Engineering Research

IC increases cost as bid item…what's it worth?

+1.1%

Source: White, D.J., Vennapusa, P., Harland, J., Quist, S. (2011). *Iowa DOT Roller Integrated Compaction Monitoring Technology Research and Implementation – Phase II (Hot Mix Asphalt)*. Final Report, Center for Earthworks Engineering Research, Iowa State University, Ames, Iowa.

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IC Research/Implementation/Educational Element Ratings – TTICC 2008-2014

Rating	2008[1]	2009[2]	2010[3]	2011[4]	2012	2014
1	Correlations	Specifications	Correlations	Correlations	Data Management	Data Management
2	Education	Correlations	Specifications	Specifications	Specifications	Education
3	Moisture Content Influence	Mechanistic QC/QA	Mechanistic QC/QA	Data Management	Correlations	Correlations
4	Data Management	Non-Uniformity	IC Advancements	Demo Projects	Non-Uniformity	Sustainability/ROI
5	Demo Projects	Data Management	Demo Projects	Education	Output Standardization	Specifications
6	Mechanistic QC/QA	Demo Projects	Non-Uniformity	Non-Uniformity	Sensor Calibration	Non-Uniformity
7	Non-Uniformity	Influence Depth	Data Management	Output Standardization	Education	Mechanistic QC/QA
8	Specifications	IC Advancements	Output Standardization	Database	Influence Depth	Influence Depth
9	Influence Depth	Education	Influence Depth	Mechanistic QC/QA	Demo Projects	Sensor Calibration
10	Promoting Best Practices	Database	Education	Influence Depth	Mechanistic QC/QA	IC Advancements
11	—	—	Database	IC Advancements	IC Advancements	Database
12	—	—	Sensor Calibration	Sustainability	Database	Demo Projects
13	—	—	—	Sensor Calibration	Sustainability	Output Standardization

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IC Research/Implementation/Educational Element Ratings – TTICC 2014 vs. 2013

Description (# of votes)	2014 ranking	2012/2013 ranking
Data Management (31)	1	1
Education (18)	2	7
Correlations (17)	3	3
Sustainability (ROI) (15)	4	13
Specifications/Guidance (14)	5	2
Non-Uniformity (13)	6	4
Mechanistic Based QC/QA (12)	7	10
Sensor Calibration (8)	8	6
Measurement Influence Depth (8)	9	8
IC Advancements (6)	10	11
Research Database (6)	10	12
Demonstrations (4)	12	9
Output Standardization (0)	13	5

Voting performed by 30 representatives from agency, industry, and academia

Handling data remains the top challenge followed by Education (Knowledge gaps), Correlations, and need to establish ROI

Picture at TTICC meeting in Harrisburg, PA on September 3-4, 2014

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IC implementation challenges

1. Easy to use data management solutions are needed
2. Engineers need proper training on interpreting IC measurements and relevant software's
3. Calibration protocols with correlating IC measurements with design parameters are needed

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Center for Earthworks Engineering Research

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

CEER Update – WOCA, ASCE Papers

Machine drive power based roller integrated compaction measurements for cohesive embankment construction

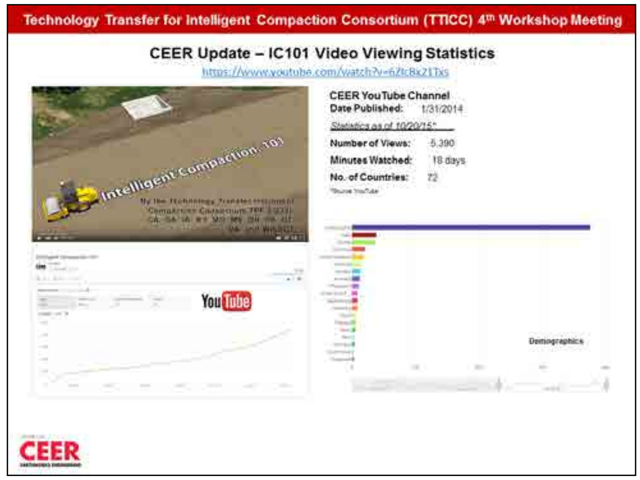
Pavana K. R. Vennapusa[1], M. ASCE and David J. White[2], M. ASCE

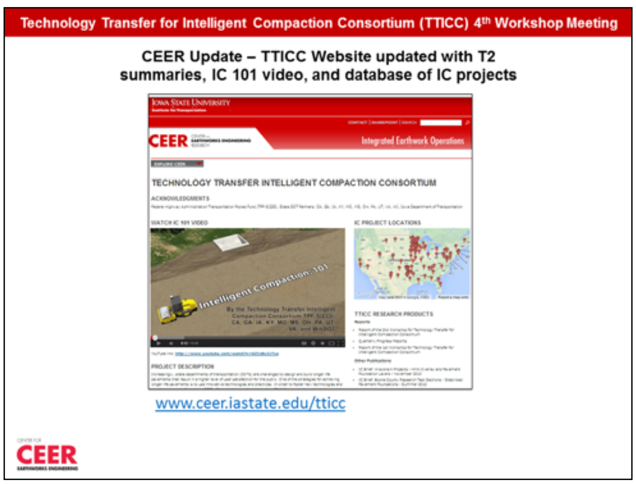
Influence of foundation support conditions on intelligent compaction measurements for hot-mix asphalt

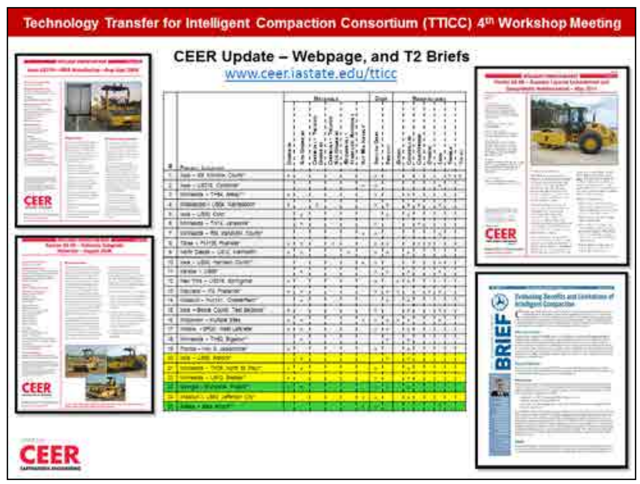
Pavana K. R. Vennapusa[1], M. ASCE and David J. White[2], M. ASCE

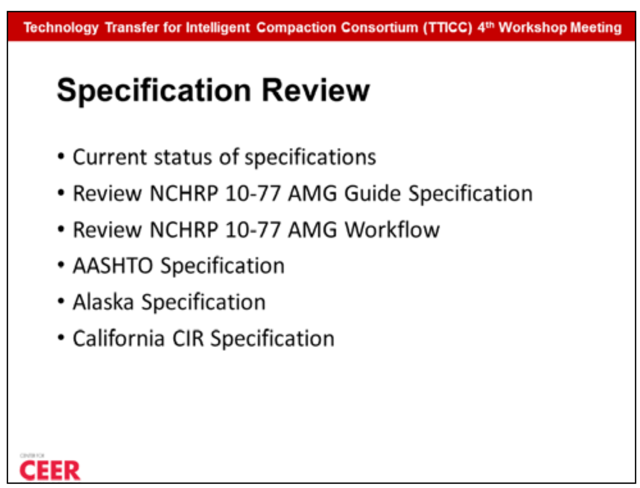
CEER

TTICC General Meeting Slides



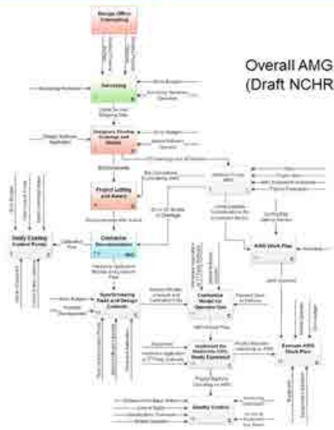






TTICC General Meeting Slides

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting



Overall AMG Workflow Processes (Draft NCHRP 1077)

CEER

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

Pavement Recycling with Intelligent Compaction – CalTrans Specification Section 30-6

- Requires *Mapping Existing Pavement* prior to CIR mix design
- IC roller key features
  - Temperature
  - Pass count and coverage
  - IC-MVs (stiffness based value)
  - RTK-GPS
- Quality Control
  - Roller passes should comply with target determined from test trip

CEER

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

Pavement Recycling with Intelligent Compaction – CalTrans Specification Section 30-6

- Test Strip for Target Values
  - 500 ft long x full width
  - NG testing every pass (3 locations) to establish break over point
  - 10 NG tests after break over point pass
  - Create compaction curves using Veda for NG and IC-MVs
  - Target # Passes = Passes associated with break over point density ?
- Production CIR Compaction
  - 90% of area > Target # Passes determined from Test Strip

CEER

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

Intelligent Compaction for Hot Mix Asphalt – CalTrans Specification Section 39-8

- IC for HMA on breakdown and intermediate rollers
- IC roller key features
  - Temperature
  - Pass count and coverage
  - IC-MVs (stiffness based value)
  - RTK-GPS
- Quality Control
  - Roller passes should comply with target determined from test trip
  - HMA temperature for first coverage of breakdown compaction
  - HMA temperature at the completion of intermediate compaction
  - IC-MVs only if HMA > 0.15 ft thick

CEER

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

Intelligent Compaction for Hot Mix Asphalt – CalTrans Specification Section 39-8

- Test Strip for Target Values – Targets???
  - 600 ft long x full width
  - NG testing every pass (3 locations) until it remains constant or decreases
  - 10 NG tests after final pass
  - **Target Density** = Peak NG Density (or Avg.?) achieved within the compaction temperature range for the mixture
  - **Target IC-MV** = IC-MV with < 5% increase compared to the previous pass (Avg. ?)
  - **Target IC-MV** = IC-MV corresponding to specified target density (% comp) using linear regression analysis from Veda
  - **Target # of Passes (not clearly defined)???**

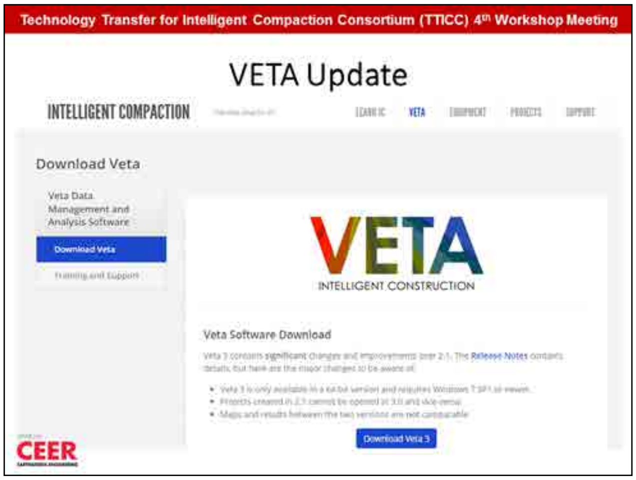
CEER

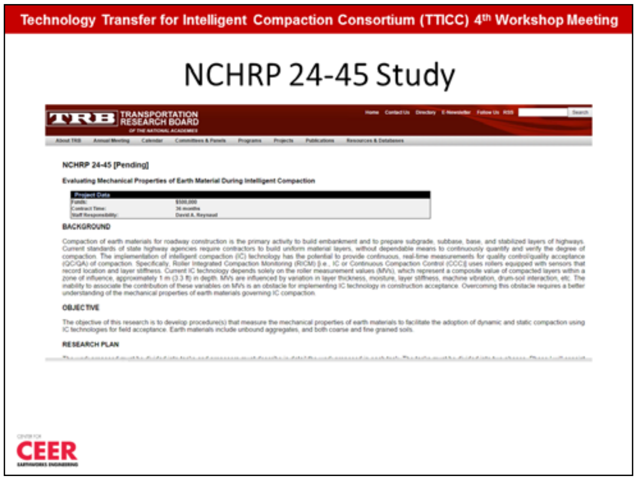
Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting

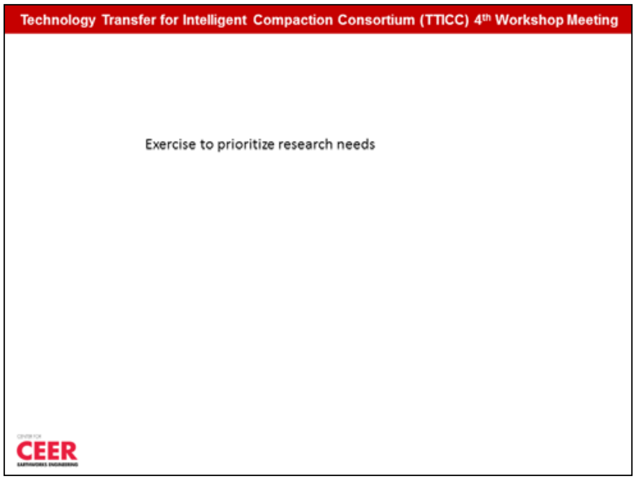
Intelligent Compaction for Hot Mix Asphalt – CalTrans Specification Section 39-8

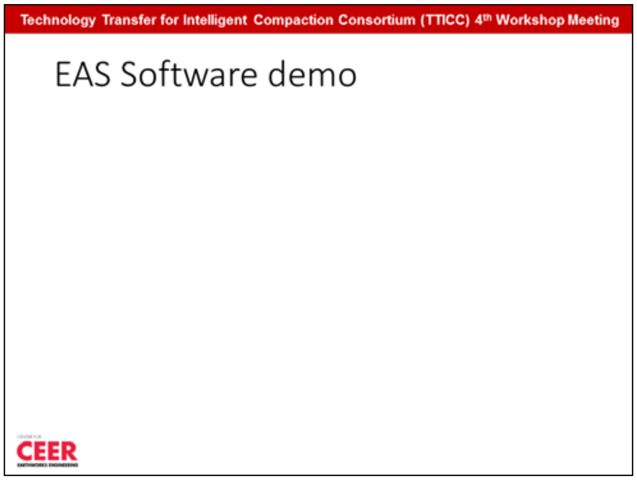
- Production HMA Compaction
  - **Pass Count:** 90% of area > Target determined from Test Strip
  - **Temperature:** ≥ 95% of area within +/- Specified Range
  - **IC-MVs:** If IC-MV < 90% of Target Value (from test strip), perform NG test for compliance
  - If IC-MV < 80% of Target Value, establish a new target value.
- Question: Do these parameter settings relate to desired quality and smoothness?
- Question: How will contractor implement?

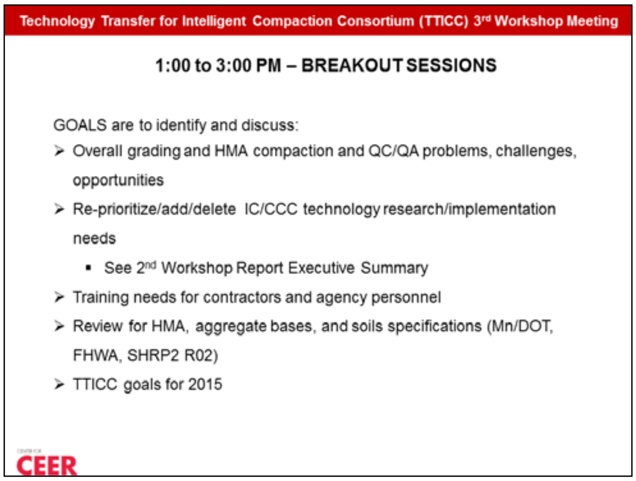
CEER

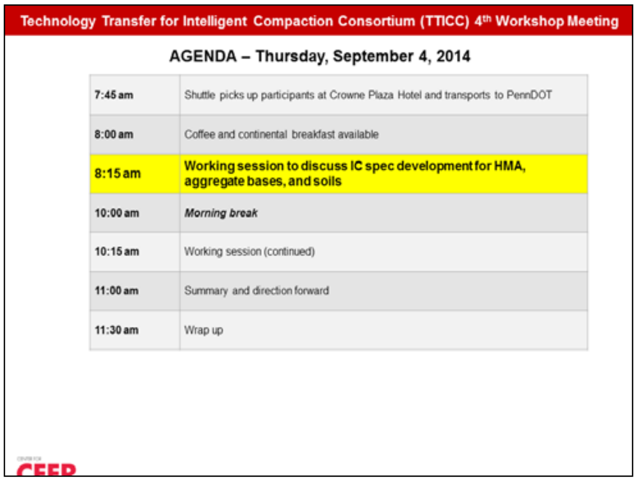

Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting
VETA Update
INTELLIGENT COMPACTION
Download Veta
Veta Data Management and Analysis Software
Download Veta
VETA
INTELLIGENT CONSTRUCTION
Veta Software Download
Download Veta 3
CEER


Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting
NCHRP 24-45 Study
TRB TRANSPORTATION RESEARCH BOARD
NCHRP 24-45 [Pending]
Evaluating Mechanical Properties of Earth Material During Intelligent Compaction
BACKGROUND
OBJECTIVE
RESEARCH PLAN
CEER


Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting
Exercise to prioritize research needs
CEER


Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting
EAS Software demo
CEER


Technology Transfer for Intelligent Compaction Consortium (TTICC) 3rd Workshop Meeting
1:00 to 3:00 PM – BREAKOUT SESSIONS
GOALS are to identify and discuss:
Overall grading and HMA compaction and QC/QA problems, challenges, opportunities
Re-prioritize/add/delete IC/CCC technology research/implementation needs
See 2nd Workshop Report Executive Summary
Training needs for contractors and agency personnel
Review for HMA, aggregate bases, and soils specifications (Mn/DOT, FHWA, SHRP2 R02)
TTICC goals for 2015
CEER


Technology Transfer for Intelligent Compaction Consortium (TTICC) 4th Workshop Meeting
AGENDA – Thursday, September 4, 2014
7:45 am
Shuttle picks up participants at Crowne Plaza Hotel and transports to PennDOT
8:00 am
Coffee and continental breakfast available
8:15 am
Working session to discuss IC spec development for HMA, aggregate bases, and soils
10:00 am
Morning break
10:15 am
Working session (continued)
11:00 am
Summary and direction forward
11:30 am
Wrap up
CEER

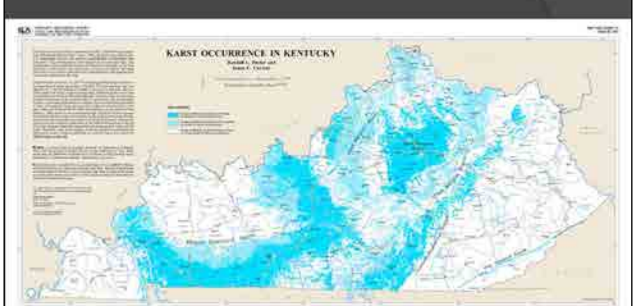
HISTORY OF IC IN KY

Outline

- Pre-History
- Middle Ages
- Renaissance
- Back to the Future!

About Kentucky

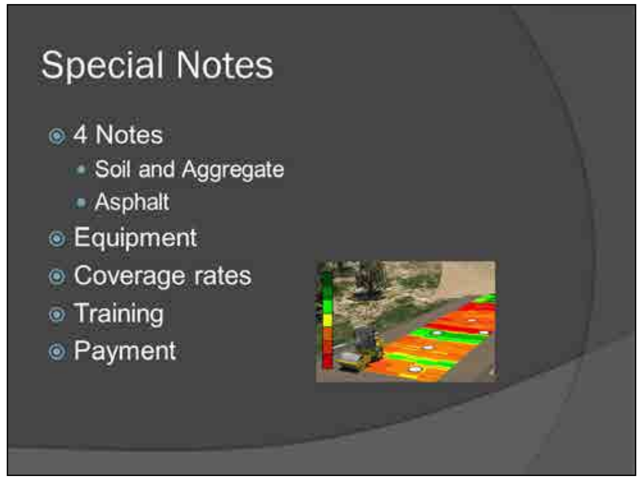
- http://kgs.uky.edu/kgsmap/basemap/viewer.asp
- East KY mountains
- West KY flat lands deep soils
- Rolling hills in the middle
- Caves, mines, Horses and sinkholes

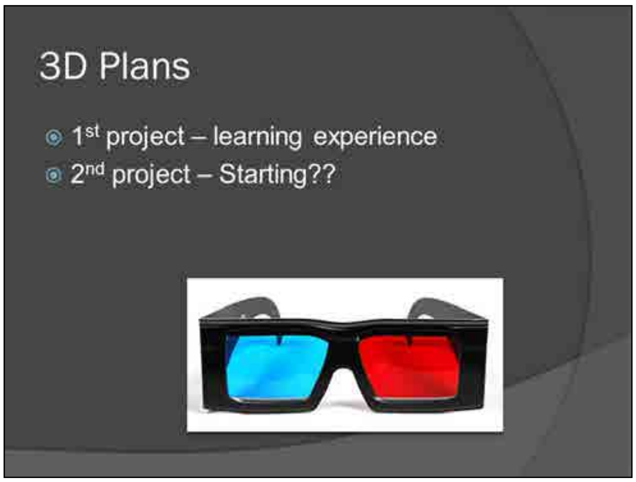


Early Years

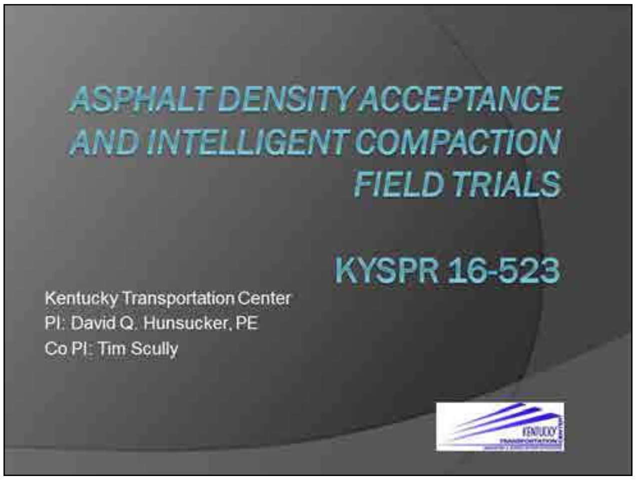
- No Nukes!!
- What is IC?
- Show me the $$$

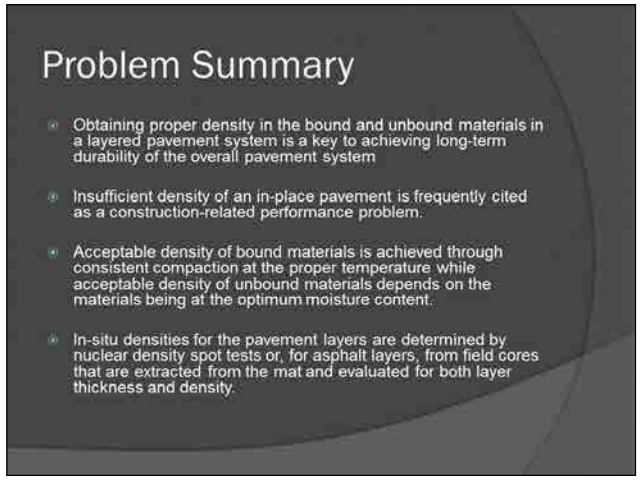
History of IC in Kentucky

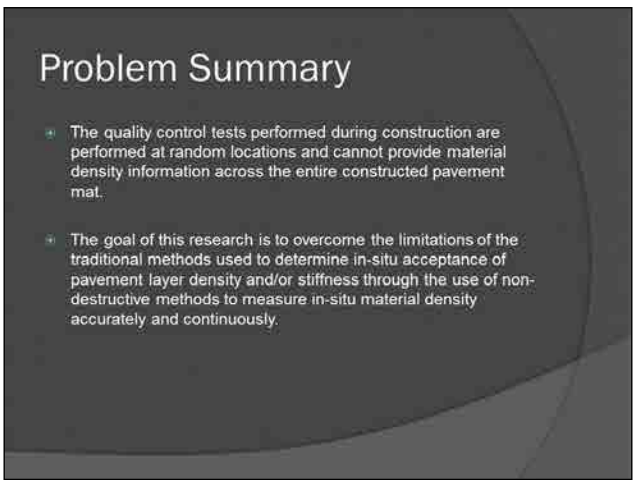


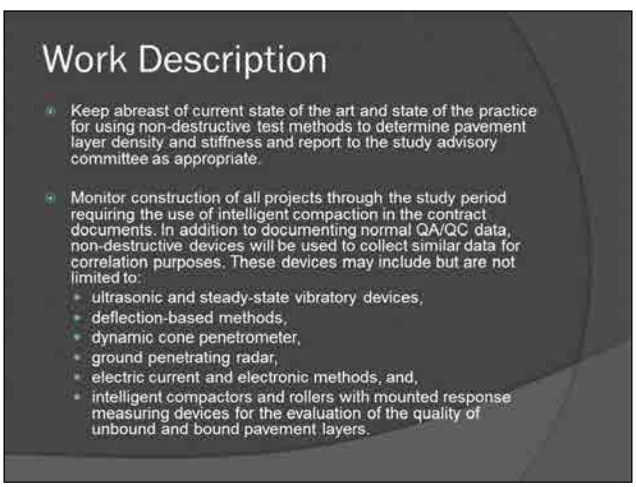


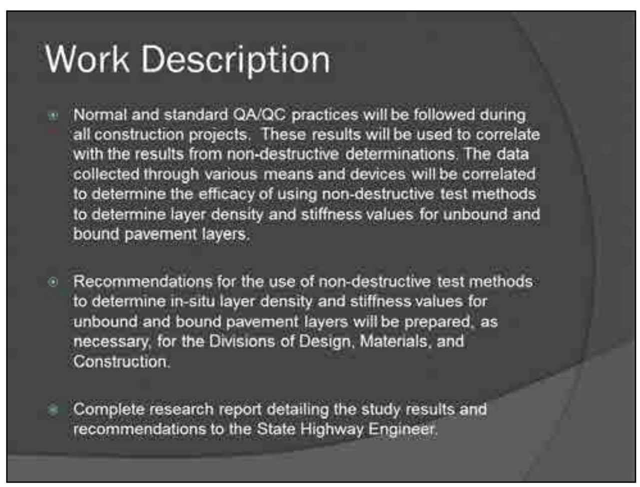
Asphalt Density Acceptance and Intelligent Compaction Field Trials, by David Q. Hunsucker











Intelligent Compaction Update, by Daniel E. Clark

INTELLIGENT COMPACTION UPDATE

IC-TP ETG Meeting No. 5
October 21, 2015

Daniel E. Clark, P.E.
PennDOT Central Office
Innovation & Support Services Division
717.787.3137

pennsylvania
DEPARTMENT OF TRANSPORTATION

PennDOT Updates and Feedback
Objectives

Use the intelligent compaction data to monitor and improve the quality of the construction.

Roller operator is the first responder - monitors the IC data and reports suspicious quality to superiors.

Managers review data and decide if action is required.

2

PennDOT Updates and Feedback
Lessons Learned

- Set-up is not fool-proof
- Trees overhanging roadways
- Equipment staging areas
- Electrical lines and transformers
- Shallow bedrock
- Scale effects
- Other states

3

PennDOT Updates and Feedback
Lessons Learned – Equipment Set Up

Setting up the intelligent compaction equipment has so far been conducted by the manufacturer's representatives / experts. As the use of IC expands, it will not be possible for the 1st line factory representatives to be at every site every time.

Other people will need to be trained to assist them in setting up the equipment – and the proof of the training comes during construction.

4

PennDOT Updates and Feedback
Lessons Learned – Equipment Set Up

On a number of our projects, the contractors have been practicing with the IC equipment on other layers or roadways in advance of the required item(s). This is a good system check for the contractor.

Should we require or just recommend these practice runs?

PennDOT Updates and Feedback
Lessons Learned - Trees

We first observed the effect of trees over-hanging the road-ways last year on ECMS 91146 in District 11. There were a couple of hundred feet at this site where the trees blocked the GPS signals.

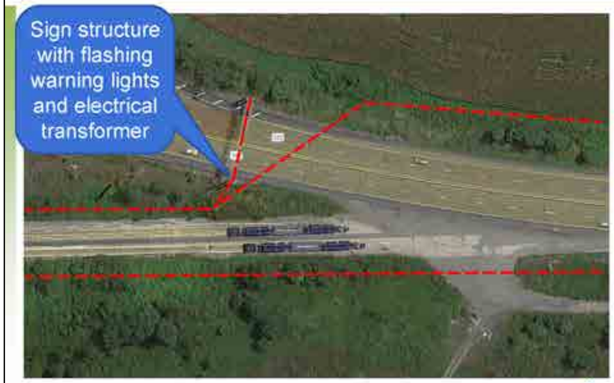
Intelligent Compaction Update, by Daniel E. Clark

PennDOT Updates and Feedback
Lessons Learned – Equipment Staging Area

On ECMS 8212, the rollers were parked off the side of the road (under some trees). When the IC equipment was started up the next night, it did not get a clear signal. However, that was not apparent until the roller moved out from under the trees. Then the signal shifted to where it should have been and the shift in the signal caused quite a stir!

7

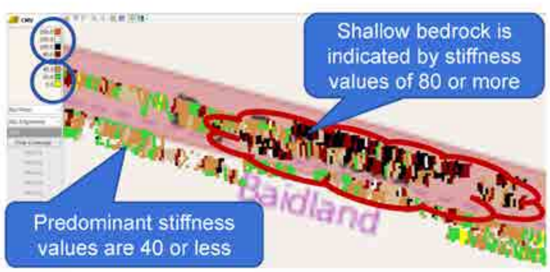
PennDOT Updates and Feedback
Lessons Learned – Stray Currents



8

PennDOT Updates and Feedback
Lessons Learned – Shallow Bedrock

Shallow bedrock was encountered on ECMS 96936 in District 12-0.



9

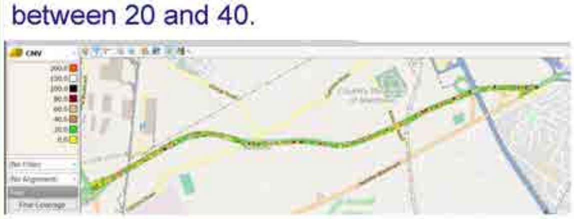
PennDOT Updates and Feedback
Lessons Learned – Scale Effects

- When evaluating the IC data, the user can set the intervals and the colors of the scales of the graphs. You may choose large intervals with similar colors which give the impression of consistent (good quality) data. Or you may choose small intervals with contrasting colors and the same data will appear to be inconsistent (poor quality) data.

10

PennDOT Updates and Feedback
Lessons Learned – Scale Effects – D5 - Stiffness

Stiffness overview: Green seems to be the predominant color, indicating a stiffness of between 20 and 40.



11

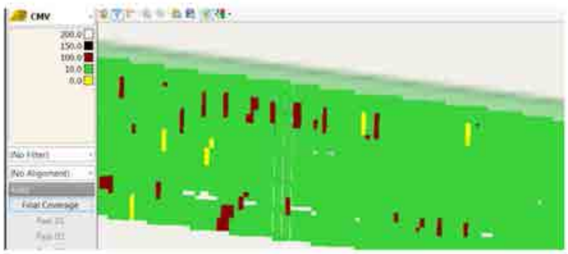
PennDOT Updates and Feedback
Lessons Learned – Scale Effects – D5 - Stiffness

Stiffness detail: In this detail, it is apparent that there is a significant amount of brown mixed in with the green.

12

PennDOT Updates and Feedback
Lessons Learned – Scale Effects – D5 - Stiffness

Stiffness detail: By changing the scales, we can make most of the variation go away … So, what is the right scale to use?



13

PennDOT Updates and Feedback
Lessons Learned – Other States

Other states are using infrared paver bars attached to the back of their pavers to obtain a temperature profile across the width of the mat as it is being laid down. This provides additional information about the operation of the paver.

We are not sure if the paver bar provides better intel than the IC or if this supplements the IC data, and at what cost.

14

PennDOT Updates and Feedback
Lessons Learned – Other States

Some states are requiring that all rollers be equipped with IC devices. Presently, PennDOT only requires the breakdown roller be IC equipped because it is the one that does most of the compaction work.

However, we are beginning to see the value of equipping all the rollers with IC and we may pursue this in the future.

15

PennDOT Updates and Feedback
Project Statistics

- We have had IC projects in 10 of our 11 Engineering Districts.
- We have had multiple IC projects in Districts 9(2), 10(2), 11(4), 12(6) in the western part of the state.
- 13 IC projects have been completed
- 5 IC projects are under construction
- 2 IC projects are in design

16

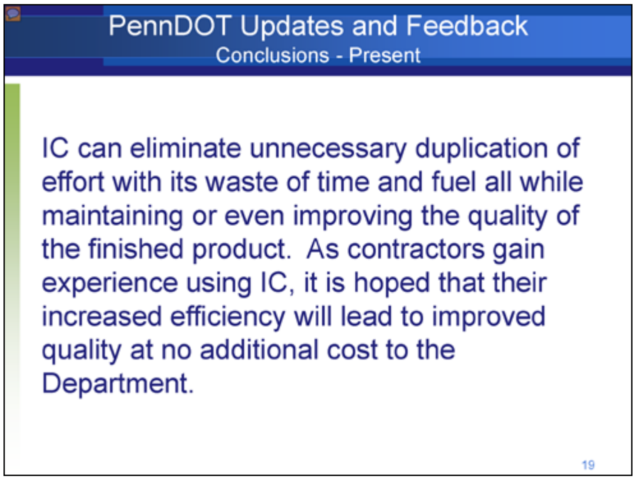
PennDOT Updates and Feedback
Project Statistics

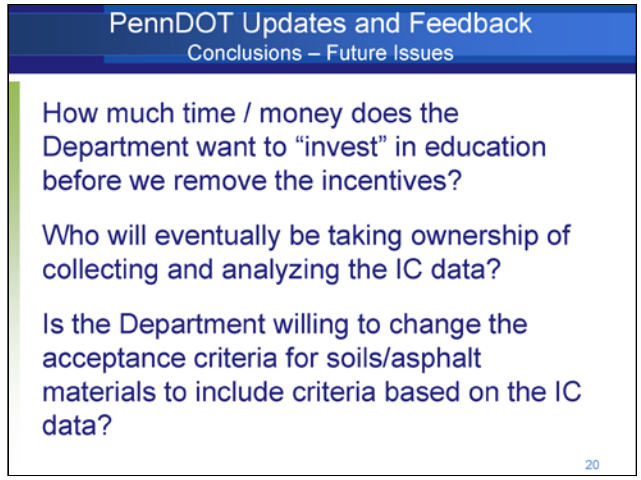
- We now have bid prices on 17 projects for a total of $256 M of construction costs including just over $1 M in IC costs.
- The “average” cost for an IC project is $64,000 with prices ranging from $20,000 to $164,000.

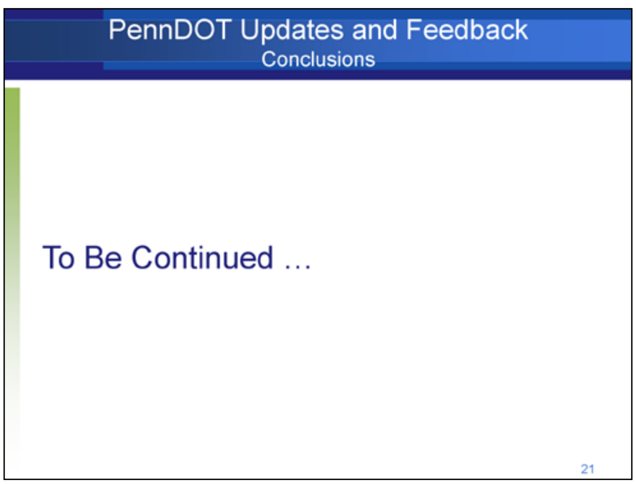
PennDOT Updates and Feedback
Project Statistics

- Unbalanced bidding: A contractor loaded the training budget ($80,000) and bid $0.01 / SY for the production work, risking $1800 on the IC portion of the $3.7 M construction contract. The contractor’s bidding strategy successfully countermanded any attempt on our part to deduct appropriate payment for deficiencies (which did occur) in gathering the IC data.

Intelligent Compaction Update, by Daniel E. Clark







Appendix D: Workshop Products

The following is a list of the products provided for the workshop participants. These are included in the following pages.

1. List of Intelligent Compaction Briefs
2. Report of the 3rd Workshop for Technology Transfer for Intelligent Compaction Consortium (available for download from www.ceer.iastate.edu/tticc)
3. List of IC Specifications Developed for Soils and HMA in United States
4. NCHRP 10-77 AMG Guide Specifications
5. NCHRP 10-77 AMG Workflow Process
6. List of IC Technical Publications

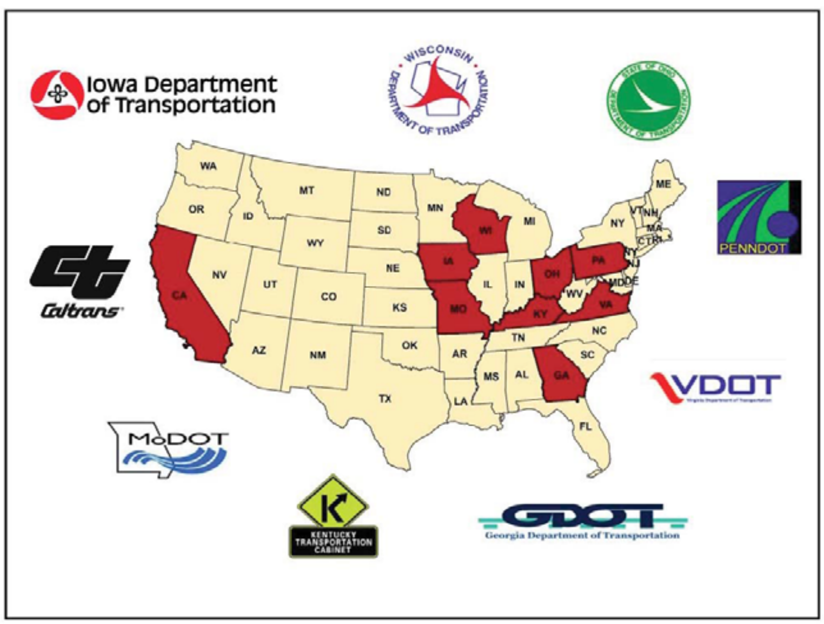
Technology Transfer Intelligent Compaction Consortium (TTICC) – TPF-5(233)
List of Intelligent Compaction (IC) Briefs

#	Project Location	Materials: Granular	Materials: Non Granular	Materials: Chemically Treated Granular	Materials: Chemically Treated Non Granular	Materials: Mechanically Stabilized Materials	Materials: Hot Mix Asphalt	Drum: Smooth Drum	Drum: Padfoot	Manufacturer: Bomag	Manufacturer: Caterpillar	Manufacturer: Case/Ammann	Manufacturer: Dynapac	Manufacturer: Sakai	Manufacturer: Trimble	Manufacturer: Volvo
1	Iowa – I29, Monona County*	X						X							X	X
2	Iowa – US218, Coralville*						X	X						X		
3	Minnesota – TH64, Akeley**	X						X			X					
4	Mississippi – US84, Waynesboro*	X		X				X	X		X	X		X		
5	Iowa – US30, Colo*		X						X		X					
6	Minnesota – TH14, Janesville*		X					X				X				
7	Minnesota – Rt4, Kandiyohi County*						X	X						X		
8	Texas – FM156, Roanoke*	X	X		X			X	X			X	X			
9	North Dakota – US12, Marmarth*	X	X			X		X	X		X					
10	Iowa – US30, Harrison County**						X	X						X		
11	Kansas – US69*		X					X	X		X			X		
12	New York – US219, Springville*	X						X		X	X					
13	Maryland – I70, Frederick*	X	X					X	X	X			X	X		
14	Missouri – Hwy141, Chesterfield**		X						X		X					
15	Iowa – Boone County Test Sections*	X						X			X			X		
16	Wisconsin – Multiple Sites	X	X				X	X	X	X	X			X		
17	Indiana – SR25, West Lafayette*	X	X					X	X		X					
18	Minnesota – TH60, Bigelow**		X						X		X					
19	Florida – Hwy 9, Jacksonville*	X						X			X					
20	Iowa – US65, Altoona*		X						X		X					
21	Minnesota – TH36, North St. Paul**	X	X					X			X					
22	Minnesota – US10, Staples**	X						X			X					
23	Georgia – Brunswick Project**	X	X					X	X		X					
24	Missouri – US63, Jefferson City*						X	X			X					
25	Alaska – Sitka Airport**						X	X						?		

*Research/Demonstration Projects
** Projects with IC Specifications
IC briefs completed and posted on CEER website
IC Briefs In Preparation By ISU
Information Requested from DOTs

Report of the 3rd Workshop for Technology Transfer for Intelligent Compaction Consortium

March 2015



Sponsored through Transportation Pooled Fund TPF-5(233)

CEER CENTER FOR EARTHWORKS ENGINEERING RESEARCH

IOWA STATE UNIVERSITY
Institute for Transportation

Executive Summary

On September 3–4, 2014, the Pennsylvania DOT hosted the 3rd workshop for the Technology Transfer for Intelligent Compaction Consortium (TTICC), a Transportation Pooled Fund (TPF-5(233)) initiative designed to identify, support, facilitate, and fund intelligent compaction (IC) research and technology transfer initiatives. The following were the key objectives of the workshop:

- Review and exchange experiences of state DOTs in implementing IC for earthwork and HMA
- Review TTICC IC case history summaries
- Facilitate a collaborative exchange of information between state DOTs, FHWA, and industry to accelerate effective implementation of IC technologies
- Update the IC roadmap for identifying key research/implementation/education needs, and action items for TTICC group, FHWA, and industry

The workshop's attendees—representing 10 state DOTs, the Federal Highway Administration (FHWA), Hamm/Writgen America, Groff Tractor and Equipment, SITECH Allegheny, AB Consultants, and Iowa State University—reviewed IC case history summaries, discussed recent IC pilot specifications implemented by state DOTs or demonstration projects conducted by state DOTs, and voted and brainstormed IC research, implementation, and educational needs.

A key outcome of the workshop was the evaluation and update of the IC Road Map, a prioritized list of IC technology research/implementation needs initially created in a 2008 IC workshop meeting and updated in 2009, 2010, 2011, and 2012 workshops. The top three IC research/implementation needs are now (1) data management and analysis, (2) education/certification programs for IC, and (3) correlations between IC and in situ test measurements. The revised IC road map is presented in Table 1. After updating the IC roadmap, the group identified action items for the TTICC group, FHWA, and industry for advancing the top five road map elements.

This workshop served as a forum to facilitate information exchange and collaboration and developing a list of action items to advance and accelerate implementation of IC technology into earthwork and asphalt construction practice and developing a short list of items that the TTICC team can use to help advance the IC road map research/implementation priorities.

— Report of the 3rd Workshop for Technology Transfer for Intelligent Compaction Consortium

Table 1. Prioritized IC technology research/implementation needs – 2014 TTICC workshop

Prioritized IC/CCC Technology Research/Implementation Needs

1. Data Management and Analysis (31*)
2. Education Program/Certification Program (18*)
3. Intelligent Compaction and In Situ Correlations (17*)
4. Sustainability/ROI (15*)
5. Intelligent Compaction Specifications/Guidance (14*)
6. Understanding Impact of Non-Uniformity of Performance (13*)
7. In Situ Testing Advancements and New Mechanistic Based QC/QA (12*)
8. Standardization of Roller Sensor Calibration Protocols (8*)
9. Understanding Roller Measurement Influence Depth (8*)
10. Intelligent Compaction Technology Advancements and Innovations (6*)
11. Intelligent Compaction Research Database (6*)
12. Project Scale Demonstration and Case Histories (4*)
13. Standardization of Roller Outputs and Format Files (0*)

*total votes are provided in parenthesis

Table 2. IC/CCC research, implementation, and educational elements, ratings from 2008 to 2014

Rating	2008[1]	2009[2]	2010[3]	2011[4]	2012	2014
1	Correlations	Specifications	Correlations	Correlations	Data Management	Data Management
2	Education	Correlations	Specifications	Specifications	Specifications	Education
3	Moisture Content Influence	Mechanistic QC/QA	Mechanistic QC/QA	Data Management	Correlations	Correlations
4	Data Management	Non-Uniformity	IC Advancements	Demo Projects	Non-Uniformity	Sustainability/ ROI
5	Demo Projects	Data Management	Demo Projects	Education	Output Standardization	Specifications
6	Mechanistic QC/QA	Demo Projects	Non-Uniformity	Non-Uniformity	Sensor Calibration	Non-Uniformity
7	Non-Uniformity	Influence Depth	Data Management	Output Standardization	Education	Mechanistic QC/QA
8	Specifications	IC Advancements	Output Standardization	Database	Influence Depth	Influence Depth
9	Influence Depth	Education	Influence Depth	Mechanistic QC/QA	Demo Projects	Sensor Calibration
10	Promoting Best Practices	Database	Education	Influence Depth	Mechanistic QC/QA	IC Advancements
11	—	—	Database	IC Advancements	IC Advancements	Database
12	—	—	Sensor Calibration	Sustainability	Database	Demo Projects
13	—	—	—	Sensor Calibration	Sustainability	Output Standardization

Table 3. Revised IC road map research, implementation, and educational elements, 2nd TTICC workshop

IC Road Map Research, Implementation, and Educational Elements

1. **Data Management and Analysis [1*].** The data generated from IC compaction operations is 100+ times more than traditional compaction QC/QA operations and presents new challenges. The research element should focus on data analysis, visualization, management, and be based on a statistically reliable framework that provides useful information to assist with the construction process control. This research element is cross cutting with elements 2, 3, 5, 7, 8, 11, and 12.

2. **Education Program/Certification Programs [7*].** This educational element will be the driver behind IC technology and specification implementation. Materials generated for this element should include a broadly accepted and integrated certification program that can be delivered through short courses and via the web for rapid training needs. Operator/inspector guidebook and troubleshooting manuals should be developed. The educational programs need to provide clear and concise information to contractors and state DOT field personnel and engineers. A potential outcome of this element would be materials for NHI training courses.

3. **Intelligent Compaction and In Situ Correlations [3*].** This research element will develop field investigation protocols for conducting detailed correlation studies between IC measurement values and various in situ testing techniques for earth materials and HMA. Standard protocols will ensure complete and reliable data collection and analysis. Machine operations (speed, frequency, vibration amplitude) and detailed measurements of ground conditions will be required for a wide range of conditions. Relationships between HMA and WMA mix temperature, roller measurement values, and performance should be developed. A comprehensive research database and methods for establishing IC target values will be the outcome of this study. Information generated from this research element will contribute to elements 2, 7, 8, 10, and 12. There is a need to define "gold" standard QC/QA in situ test measurement for correlations depending on the material type (i.e., soils, base, or asphalt).

4. **Sustainability/Return of Investment (ROI) [12*].** This research element involves evaluating benefits of IC in terms of sustainability aspects such as the potential for use of less fuel during construction, reduced life-cycle and infrastructure maintenance costs, etc.

5. **Intelligent Compaction Specifications/Guidance [2*].** This research element will result in several specifications encompassing method, end-result, performance-related, and performance-based options. This work should build on the work conducted by various state DOTs, NCHRP 21-09, and the ongoing FHWA IC Pooled Fund Study 954. The new specifications should be technology independent and should allow use of different QC/QA testing devices and IC measurement values. This research element is cross cutting with elements 3, 5, 6, 7, and 8.

6. **Understanding Impact of Non-Uniformity on Performance [4*].** This track will investigate relationships between compaction non-uniformity and performance/service life of infrastructure systems—specifically pavement systems. Design of pavements is primarily based on average values, whereas failure conditions are affected by extreme values and spatial variations. The results of the research element should be linked to MEPDG input parameters. Much needs to be learned about spatial variability for earth materials and HMA and the impact on system performance. This element is cross cutting with elements 1, 2, and 7.

7. **In Situ Testing Advancements and New Mechanistic Based QC/QA [10*].** This research element will result in new in situ testing equipment and testing plans that target measurement of performance related parameter values including strength and modulus. This approach lays the groundwork for better understanding the relationships between the characteristics of the geo-materials used in construction and the long-term performance of the system.

*1st TTICC workshop rating.

Table 3. Revised IC road map research, implementation, and educational elements, 4th TTICC workshop

8. **Standardization of Roller Sensor Calibration Protocols [6*].** IC rollers are equipped with measurement sensors (e.g., accelerometers in the case of vibratory-based technologies), GPS, data logging systems, and many on-board electronics. These sensors and electronics need periodic maintenance and calibration to ensure good repeatability in the measurement systems. This research element will involve developing a highly mobile mechanical system that could simulate a range of soil conditions and be deployed to a project site to periodically verify the roller output values. Further, establishment of a localized calibration center (similar to a falling weight deflectometer calibration center) by a state agency can help state agencies periodically verify the repeatability and reproducibility of the measurements from their sensors and other electronics.

9. **Understanding Roller Measurement Influence Depth [8*].** Potential products of this research element include improved understanding of roller operations, roller selection, interpretation of roller measurement values, better field compaction problem diagnostics, selection of in situ QA testing methods, and development of analytical models that relate to mechanistic performance parameter values. This element represents a major hurdle for linking IC measurement values to traditional in situ test measurements.

10. **Intelligent Compaction Technology Advancements and Innovations [11*].** Potential outcomes of this research element include development of improved IC measurement systems, addition of new sensor systems such as moisture content and mat core temperature, new onboard data analysis and visualization tools, and integrated wireless data transfer and archival analysis. Further, this research element will also explore retrofitting capabilities of IC measurement systems on existing rollers. It is envisioned that much of this research will be incremental and several sub-elements will need to be developed.

11. **Intelligent Compaction Research Database [12*].** This research element would define IC project database input parameters and generate web-based input protocols with common format and data mining capabilities. This element creates the vehicle for state DOTs to input and share data and an archival element. In addition to data management/sharing, results should provide an option for assessment of effectiveness of project results. Over the long term the database should be supplemented with pavement performance information. It is important for the contractor and state agencies to have standard guidelines and a single source for the most recent information. Information generated from this element will contribute to elements 2, 3, 7, 9, and 10.

12. **Project Scale Demonstration and Case Histories [9*].** The product from this research element will be documented experiences and results from selected project level case histories for a range of materials, site conditions, and locations across the United States. Input from contractor and state agencies should further address implementation strategies and needed educational/technology transfer needs. Conclusive results with respect to benefits of IC technology should be reported and analyzed. Information from this research element will be integrated into elements 1, 2, 4, and 7.

13. **Standardization of Roller Outputs and Format Files [5*].** This research element involves developing a standardized format for roller output and format files. This element crosscuts with specification element 2.

*2nd TTICC workshop (2012) rating.

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Table 4. Updated action items for the TTICC project team, industry, and FHWA

List of Action Items	TTICC	Industry	FHWA
1. Data Management and Analysis			
a. Define requirements (how to deal with legal issues in data sharing, and how to archive data)	x[1]		
b. Discuss with other state DOTs	x		
c. Enhance Capabilities of Software's		x	
d. Need Real Time Data Processing/Delivery Capabilities		x	
e. Identify Future Use Needs for Data	x		x
2. Education and Certification Programs			
a. Develop Videos (IC101, 201, 202)	x[2]		
b. Operator Training Programs		x	
c. Certifications for IC Data	x		
3. IC and In Situ Correlations			
a. Develop a Standard Calibration Procedure (Nonnuclear Gauge)	x[3]		
b. Problem Statement to Better Assess Influence of Moisture Content	x		
d. Support Research Efforts			x
4. Sustainability/Return of Investment (ROI)			
a. Develop a Green Value Proposition	x		
b. Cost Information (Capital and Life-Cycle)	x		
c. Improvement in Safety	x		x
6. IC Specifications/Guidance			
a. Post Examples and Current Specifications Online (Use CEER Website)	x		
b. Establish a Review Committee	x		
c. Create Online Mechanism to Track Document Updates (versions)	x		
d. Be Informed of TTICC Activities (CEER Website)		x	x
e. Review Specifications		x	x
f. Share TTICC Vision		x	

[1]Identify GIS data archival protocal (1 page)
[2]Develop IC101 3 minute version video
[3]NCHRP synthesis on existing correlations

List of IC Specifications for Soils and HMA in United States

Technology Transfer for Intelligent Compaction Consortium (TTICC) TPF-5(233)
4th Workshop Meeting, October 26-28, 2015

LIST OF IC SPECIFICATIONS FOR SOILS AND HMA IN UNITED STATES UPDATED_10/20/15

Developed By	HMA (Year)	Soils (Year)
State Agency		
Alaska DOT	Yes (2014)	Yes (2015 Draft)
Arizona DOT	Yes (2014)	No
California DOT	Yes (2014) [Includes CIR]	No
Georgia DOT	Yes (2012)	Yes (2012)
Iowa DOT	Yes (2013)	Yes (2010)
Indiana DOT	Yes (2014)	No
Kentucky DOT	Yes (2015)	Yes (2015)
Massachusetts DOT	Yes (2013)	No
Michigan DOT	No	Yes (2013)
Minnesota DOT	Yes (2014)	Yes (2014)
Missouri DOT	No	Yes (2009)
North Carolina DOT	Yes (2013)	Yes (2012)
Nevada DOT	Yes (2013)	No
New Jersey DOT	Yes (2014)	No
New Mexico DOT	Yes (2014)	No
North Carolina DOT	Yes (2014)	Yes (2014)
Oklahoma DOT	Yes (2014)	No
Oregon DOT	Yes (2015)	No
Pennsylvania DOT	Yes (2014)	No
Rhode Island DOT	Yes (2013)	No
Tennessee DOT	Yes (2013)	No
Texas DOT	No	Yes (2013)
Utah DOT	Yes (2013)	No
Vermont DOT	Yes (?)	Yes (?)
Washington DC	Yes (2014)	Yes (2014)
Federal Agency		
AASHTO	Yes (2015)	Yes (2015)
Central Federal Land	Yes (2012)	No
Eastern Federal Land	Yes (2013)	
SHRP2 R07	No	Yes (2014)
FHWA (Generic Specs)	Yes (2014)	Yes (2014)

(Darft) AMG Guide Specification Tool (NCHRP 1077)

Item	Section: General (G)		☑
G.01	Roadway construction may be performed utilizing automated machine guidance (AMG) system(s) in accordance with the standard specifications, special provisions, and contract documents.		☐
G.02	AMG is defined as the utilization of positioning technologies such as global positioning systems (GPS), robotic total stations, lasers, and sonic systems to automatically guide and adjust construction equipment according to the intended design requirements.		☐
G.03	The contractor may use any type of AMG system(s) that result in compliance with the contract documents and applicable Standard Specifications.		☐
G.04	Digital terrain model (DTM) files will be created with the computer software applications MicroStation (CADD software) and GEOPAK (civil engineering software). The data files will be provided in the native formats.		☐
G.05	Electronic data is provided for the Contractor's convenience, and is not a part of the Contract.		☐
G.06	The plans indicate areas of the project where roadway construction may be accomplished with AMG systems. All other areas shall be constructed with conventional survey and construction techniques unless the contractor chooses to build the required surface model to facilitate AMG grading for those areas at no additional cost to the contracting authority.		☐
G.07	The plans indicate the areas of the project where the contracting authority is providing DTM of the roadway embankment construction.		☐
G.08	GPS is not intended for the use in constructing final surface grades.		☐
G.09	The engineer may require the contractor to revert to conventional subgrade staking methods for all or part of the work at any point during construction if, in the engineer's opinion, the GPS machine guidance is producing unacceptable results.		☐
G.10	The contractor shall convert the electronic data provided by the contracting authority into the format required by their system.		☐
G.11	Areas of the project with no DTM, the contractor may use conventional survey and construction methods unless the contractor chooses to develop the required DTM to facilitate AMG grading for those areas.		☐
	Option (none, A, or B)	A. The contractor shall submit the DTM for review to the contracting authority prior to commencing grading operations.	☐
		B. The contractor shall submit the DTM for approval to the contracting authority prior to commencing grading operations.	☐
G.13	The contracting authority will only provide the data outlined in this contract and no additional electronic data will be provided.		☐
G.12	Option (A or B)	A. The cost to develop a DTM to facilitate the use of AMG grading systems shall be included as a bid item.	☐
		B. The cost to develop a digital terrain model (DTM) to facilitate the use of AMG grading systems shall not be included as a bid item.	☐
G.__	Other:		☐
Comments:			☐

Item	Section: Liability (L)	☑
L.01	The contracting authority is responsible for safeguarding equipment provided by the contractor. The contracting authority will bear all cost to replace or repair damaged equipment provided by the contractor.	☐
L.02	To use any furnished digital terrain model (DTM) data, the contractor shall release contracting authority and its employees from all liability for the accuracy of the data and its conformance to the contract.	☐
L.03	The contracting authority does not guarantee that the electronic data accuracy or completeness, or that the data systems used by contracting authority will be directly compatible with the systems used by the contractor.	☐
L.04	Information shown on the paper plans marked with the seal (official plans as advertised) shall govern.	☐
	Option (A or B) A. Information shown on the paper plans marked with the seal (official plans as advertised) shall govern.	☐
	B. Information shown on the paper plans shall govern over the provided electronic data.	☐
L.05	The contractor shall assume the risk of error if the information is used for any purpose for which the information is not intended.	☐
L.06	The information provided shall not be considered a representation of actual conditions to be encountered during construction. Furnishing this information does not relieve the contractor from the responsibility of making an investigation of conditions to be encountered including, but not limited to site visits, and basing the bid on information obtained from these investigations, and the professional interpretations and judgments of the contractor.	☐
L.07	The Contractor understands that any manipulation of the electronic data provided by the Contracting Authority shall be taken at their own risk.	☐
L.08	If the contractor chooses to develop their own digital terrain model, the contractor shall be fully responsible for all cost, liability, accuracy and delays.	☐
L.09	The contracting authority is not responsible for the integrity of the information if it is converted to a different file format or modified in any way by the contractor.	☐
L.10	Any assumptions made about the electronic data are at the contractor's risk.	☐
L.11	The contracting authority is not responsible for any computer virus or damage the electronic data may cause to the computer systems.	☐
L.12	There will be no cost or credit to the state and no contract time extension for implementing the contractor-requested change order.	☐
L.__	Other:	☐

Comments: ☐

Item	Section: Equipment (E)		☑
E.01	The contractor may use any type of automated machine control (AMG) systems that achieves compliance with the contract documents and applicable standard specifications.		☐
	Option (Y or N)	A. The contractor may use any type of approved AMG systems that result in achieving the existing grading requirements.	☐
E.02	All equipment required to accomplish AMG grading shall be provided by the contractor.		☐
E.__	Other:		☐
Comments:			☐

Item	Section: Agency Responsibilities (AR)		☑
AR.01	The contracting authority will set the initial horizontal and vertical control network of points for the project as indicated in the contract documents.		☐
AR.02	The contracting authority will provide the project specific control network, project alignment, and coordinate system information to the contractor.		☐
	Option (Y or N)	Upon request from the contractor, the contracting authority will provide the control network and coordinate system information to the contractor.	☐
AR.03	The contracting authority will provide computer-aided design and drafting files created during the design process to the contractor for review as part of the contract documents.		☐
	Option (Y or N)	The contracting authority will develop and provide computer-aided design and drafting files created during the design process to the contractor for review as part of the contract documents.	☐
AR.04	The contracting authority will provide		☐
	Option A	the following electronic files: 1. Formats from Bentley's MicroStation suite of road design software. a. Inroads - Existing and proposed digital terrain model (.DTM) b. MicroStation - Existing and proposed surface elements – triangles 2. ASCII Format - Alignment Data Files	☐
	Option B	1. A Digital Terrain Model (DTM) of the existing and proposed design surface. 2. ASCII format - Machine Control Surface Model Files. 3. ASCII Format - Alignment Data Files	☐

Item		Section: Agency Responsibilities (AR)	☑
	Option C	the following electronic files: 1. CAD Files: a. GEOPAK TIN files representing the design surfaces. b. GEOPAK GPK file containing all horizontal and vertical alignment information. c. GEOPAK documentation file describing all of the chains and profiles. d. MicroStation primary design file. e. MicroStation cross section files. f. MicroStation ROW data file. g. MicroStation photogrammetry and text files. 2. Machine Control Surface Model Files: a. ASCII format. b. LandXML format. c. Trimble Terramodel format. Note: TIN files and surface model files of the proposed finish grade include the topsoil placement where required in the plans. 3. Alignment Data Files: a. ASCII format. b. LandXML format. 4. Trimble Terramodel format.	☐
	Option D	the following electronic files: 1. Project Control - MicroStation DGN file and ASCII file. 2. Existing Topographic Data - MicroStation DGN file(s) 3. Preliminary Surveyed Ground Surface - GeoPak TIN, if available 4. Horizontal and Vertical alignment information - GeoPak GPK file and/or MicroStation DGN file(s) 5. 2D Design line work (edge of pavement, shoulder, etc.) - MicroStation DGN file(s) 6. Cross sections - MicroStation DGN file(s), GeoPak format 7. Superelevation - MicroStation DGN file(s), GeoPak format 8. Form Grades - MicroStation DGN file(s) 9. Design Drainage - MicroStation DGN file(s)	☐
AR.05	The contracting authority shall <<approve / certify>> changes to the DTM used by AMG prior to contractor using it for grading operations to ensure compliance of the approved "Release for Construction" sealed plans.		☐
	Option (Y or N)	Submit the revised DTM to the contracting authority for review and approval 60 days prior to beginning grading operations. The submittal should include a narrative detailing change to the original DTM.	☐
AR.06	In the event the contractor presents errors with the provided electronic data, the contracting authority will determine what revisions may be required. The contracting authority will revise the contract plans, if necessary, to address errors or discrepancies that the contractor identifies. The department will provide the best available information related to those contract plan revisions.		☐
	Option (Y or N)	The contracting authority will not revise the contract paper plans or electronic data files to address errors or discrepancies that the contractor identifies.	☐

Item	Section: Agency Responsibilities (AR)	☑
AR.07	The contracting authority <<will / shall / may>> perform quality assurance checks as necessary of the contractor's machine control grading results, surveying calculations, records, field procedures, and actual staking. If the contracting authority determines that the work is not being performed in accordance with the specifications, the contracting authority <<shall / may>> order the contractor to re-construct the work to the requirements of the contract documents at no additional cost to the contracting authority.	☐
AR.08	The contracting authority <<, if necessary,>>will request the contractor to provide a <<GPS rover / GPS rover and Automatic Level>>, for use during the duration of the contract. At the end of the contract, the contracting authority will return all contractor provided equipment to the contractor.	☐
AR.09	The contracting authority will not make revisions (or enhancements) to the electron design or DTM for the convenience of importing data into the AMG system.	☐
AR.10	On projects where electronic design data is not available to bidders pre-bid, the contractor may request the data during construction. If the contractor requests electronic design data, check with the project engineer to find out if it is available. If the electronic design data is available and of the same level of quality required for the rest of the contract documents, then provide the data to the contractor. A change order is necessary when providing electronic design data to the contractor to define the terms and conditions for use of the data. If the data cannot be provided, the contractor still has the option to develop a DTM and DDM from information on the project plans.	☐
AR.__	Other:	☐

Comments: ☐

Item	Section: Contractor Responsibilities (CR)	☑
CR.01	The contractor shall demonstrate the automated machine guidance (AMG) equipment's capability to meet the tolerance specifications; and their knowledge and ability to properly operate it on a test section, as specified by the contracting authority. If the equipment fails to meet the tolerance standards or the contractor, in the contracting authority's opinion, fails to demonstrate proficiency to the equipment, the contractor shall construct the project using conventional survey and construction methods.	☐
CR.02	The contractor shall <<provide –OR– provide 8 hours of>> formal training, if requested, on the use of the AMG and the contractor's systems to the contracting authority's project personnel prior to the start of construction activities utilizing AMG. This training is for providing contracting authority project personnel with an understanding of the equipment, software, and electronic data being used by the contractor.	☐
CR.03	The contractor <<, if requested,>>shall provide the contracting authority with a <<GPS rover / GPS rover and Automatic Level>>, for use during the duration of the contract. The contractor is responsible for ensuring the equipment is serviceable and up to date with the latest project data files. At the end of the contract, the contractor shall coordinate the return of the equipment provided to the contracting authority.	☐
CR.04	Contractor shall validate all control points provided by the contracting authority.	☐

Item	Section: Contractor Responsibilities (CR)	☑
CR.05	The contractor shall establish secondary control points at locations along the length of the project and outside the project limits and/or where work is performed beyond the project limits as required by the AMG system utilized. The contractor shall comply with the requirements outlined in standard specifications and contract documents. A copy of all new control point information shall be provided to the contracting authority prior to construction activities. The contractor shall be responsible for all errors resulting from their efforts and shall correct deficiencies to the satisfaction of the contracting authority and at no additional cost to the contracting authority.	☐
CR.06	The Contractor shall provide controls points and conventional grade stakes at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for the construction of drainage and roadway structures.	☐
CR.07	The site calibration shall be checked daily at control points not used in the calibration.	☐
CR.08	Control points shall be staggered on either side of the highway to provide a good strength of figure.	☐
CR.09	The contractor shall preserve all reference points and monuments that are established by the contracting authority outside the construction limits. If the contractor fails to preserve these items, they shall be re-established by the contractor to their original quality at no additional cost to the contracting authority.	☐
CR.10	The contractor shall set grade stakes and hubs meeting the requirements outlined in the standard specifications and contract documents such that the contracting authority can check the accuracy of the construction.	☐

Item	Section: Contractor Responsibilities (CR)		☑
CR.11	The Contractor shall submit a comprehensive written AMG work plan to the contracting authority for review at least 30 days prior to use. The submittal of the AMG work plan shall be an indication of the contractor's intention to utilize AMG instead of conventional methods on the project areas and elements stated in the work plan. The contracting authority shall review the AMG work plan to ensure that the requirements are addressed. The contractor shall assume total responsibility for the performance of the system utilized in the work plan. Any update or alteration of the AMG work plan during the course of the work shall be approved and submitted to the contracting authority for determination of conformance with requirements. The AMG work plan shall describe how the AMG technology will be integrated into other technologies employed on the project. This shall include, but not limited to, the following: 1. A description of the manufacturer, model, and software version of the AMG equipment. 2. Information on the contractor's experience in the use of AMG systems to be used on the project, including formal training and field experience of project staff. 3. The primary contact, and up to one alternate, for AMG technology issues. 4. A definition of the project boundaries and scope of work to be accomplished with the AMG system. 5. A description of how the project proposed secondary control(s) is to be established. Include a list and map detailing control points enveloping the site. 6. A description of site calibration procedures including, but not limited to, equipment calibration, frequency of calibration, and information to be documented. The documentation shall contain a complete record of when and where the tests were performed and the status of each equipment item tested within or out of the ranges of required tolerances. 7. A description of the contractor's quality control procedures, including frequency and type, for checking mechanical calibration and maintenance of equipment. 8. A description of the method and frequency of field verification checks and the submission schedule of results. 9. A contingency plan in the event of failure/outage of the AMG system. 10. A schedule of DTMs intended for use on the project. This shall be submitted for review, feedback, and communication.		☐
	Option (A or B)	A. At least two week prior to the preconstruction conference, the contractor shall submit to the contracting authority for review a written AMG work plan which shall include the equipment type, control software manufacturer and version, types of work to be completed using AMG, project site calibration report, repetitive calibration methods for construction equipment and rover units to be used for the duration of the project, and local GPS base station to be used for broadcasting differential correction data to rover units.	☐
		B. One week prior to the start of grading operations the Contractor shall meet with the contracting authority to review the grading plans, quality processes, and tolerance requirements.	☐
CR.12	If the contractor selects to use AMG for fine grading and placement of base or other roadway materials, the AMG system shall use a laser or robotic total station. Details of the methods and equipment shall be included in the AMG Work Plan		☐
CR.13	The contractor shall use the alignment and control data provided by contracting authority. No localization methods will be accepted.		☐
CR.14	The contractor shall provide the contracting authority with electronic as-built construction data for the projects final construction record in a format acceptable to the contracting authority.		☐
CR.15	The contractor shall be responsible for converting the information on the plans and/or electronic data file provided by contracting authority into a format compatible with the contractor's AMG system.		☐

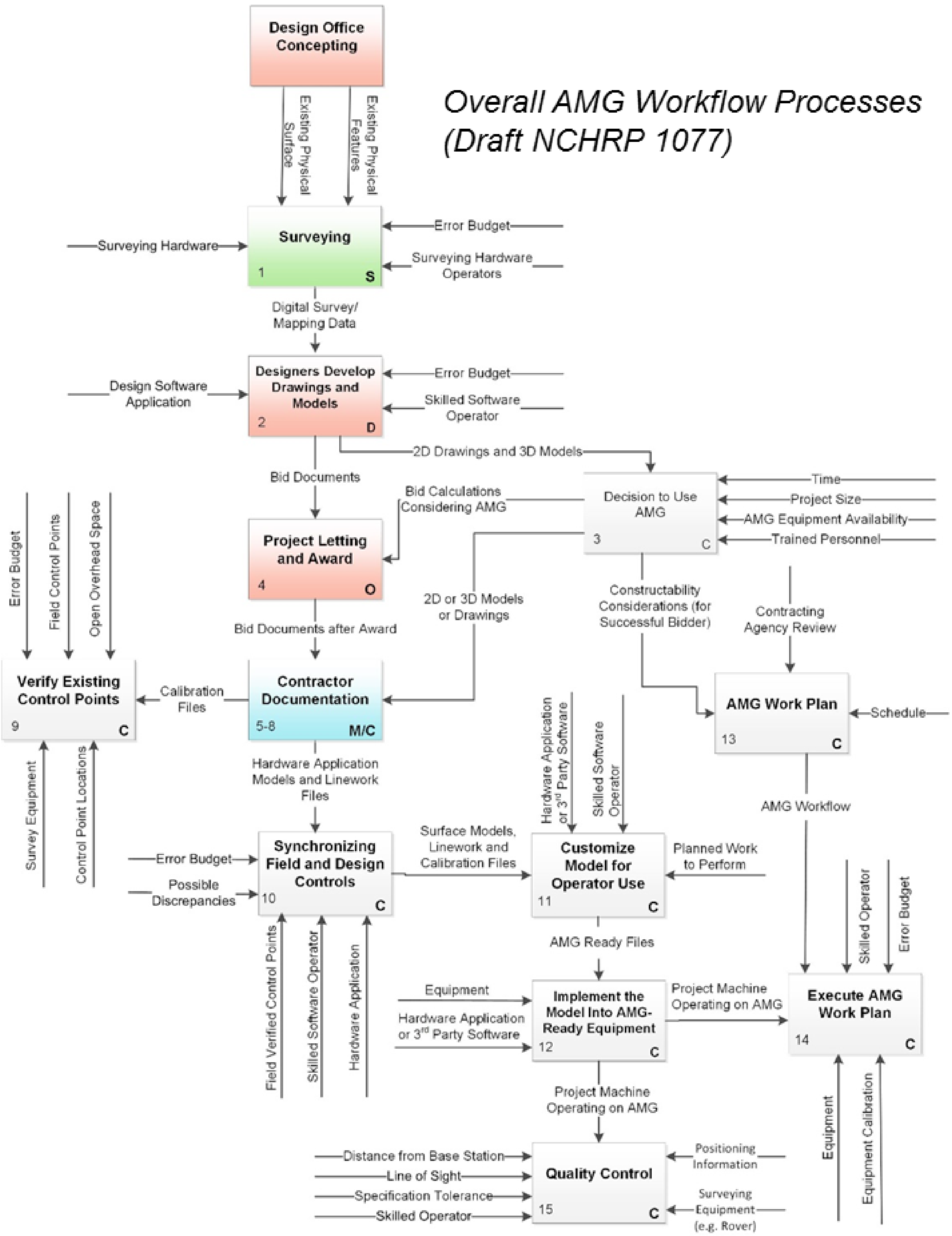
Item	Section: Contractor Responsibilities (CR)	☑
CR.16	It is the contractor's responsibility to produce the DTMs and/or 3D line work needed for AMG system, field verify the data for accuracy and conformance to the contract plans <<, and immediately report any errors to contracting authority>>.	☐
Option (Y or N)	Provide design surface DTM information to the contracting authority in a format specified by the contract documentation.	
CR.17	Revise the design surface DTM as required to support construction operations and to reflect any contract plan revisions. Perform checks to confirm DTM revisions agree with the contract plan revisions. Provide a copy of the revised design surface DTM to the contracting authority in the format defined in the contract documents.	☐
CR.18	The contractor shall meet the same accuracy requirements as detailed in the standard specifications.	☐
CR.19	The contractor shall check and recalibrate, if necessary, their AMG system at the beginning of each work day to ensure compliance with contract documents.	☐
CR.20	Grade stakes shall be established as per the standard specifications for use by the contracting authority to check the accuracy of the construction.	☐
CR.21	The contractor shall bear all costs, including but not limited to the cost of actual reconstruction work that may be incurred due to errors in application of AMG techniques or manipulation of design data in the DTM.	☐
CR.22	The contractor shall be responsible for any edits or conversions of the contracting agencies electronic data whether done by the contractor or a vendor that is hired by the contractor to perform such edits or conversions.	☐
CR.23	When AMG methods are used for any construction surveying, a licensed surveyor shall be provided by the contractor to perform verification of the final as-constructed grade report.	☐
CR.24	All changes by the contractor to the DTM data shall be submitted to the contracting authority for approval prior to use.	☐
CR.25	Any information provided by contracting authority shall not be released to any other party, corporation, business or organization except a consultant engineering firm which is employed by the contractor for work on this project. The consulting engineering firm must agree not to release the information to any other party, corporation, business or organization.	☐
CR.26	The contractor shall provide any information or data that is requested by the contracting authority for the purpose of performing the verification of quantities and quality.	☐
CR.__	Other:	☐
Comments:		☐

AMG Guide Specification Tool

Item	Section: Method of Measurement (M)	☑
M.01	The bid item for automated machine guidance grading will be measured and paid for at the lump sum contract price.	☐
	Option (Y or N) | No direct payment will be made for work required to utilize this provision. All work will be considered incidental to various grading operations.	
M.02	Earthwork volumes shall be computed by comparing and computing the difference in volumes between the existing terrain model, constructed terrain model, and final constructed terrain model whichever is applicable at the time necessary.	☐
M.03	The contracting authority will pay for costs incurred to incorporate contract plan revisions as extra work.	☐
M.__	Other:	☐
Comments:		☐

Item	Section: Payment (P)	☑
P.01	The bid item for automated machine guidance (AMG) grading will be paid for at the lump sum contract price. This payment shall be full compensation for all work associated with preparing the electronic data files for use in the contractor's AMG system, the required system check and needed recalibration, training for the Engineer, and all other items described in the standard specifications.	☐
	Option (Y or N) | The contract lump sum price bid shall include full compensation for all such surveying work including but not limited to: (1) Materials, (2) Equipment, (3) Labor, (4) Office work (preparing the electronic data files for use in the Contactor's machine control grading system, developing or building a DTM to facilitate the GPS machine control grading system, and all other calculations required to complete the work), (5) Test section as specified by the Project Engineer, (6) Training for <<agency >>project personnel, and (7) Final as-constructed grade report.	☐
P.02	Delays due to satellite reception of signals to operate the GPS machine control system will not result in adjustment to the "Basis of Payment" for any construction items or be justification for granting contract extensions.	☐
P.__	Other:	☐
Comments:		☐

Overall AMG Workflow Processes



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Appendix E: Workshop Evaluation Comments

SUMMARY OF EVALUATIONS

Technology Transfer for Intelligent Compaction Consortium (TTICC)
October 27–28, 2015 — Frankfort, KY
Total Respondents: 9

Attendees rated the following between 1 and 5.

	Very Good		Okay		Needs Improvement	Average Rating
1. Topics covered	1	2	3	4	5	1.22
2. Organization of the program	1	2	3	4	5	1.22
3. Speakers knowledgeable	1	2	3	4	5	1.22
4. Facilities were accommodating	1	2	3	4	5	1.44
5. Program met expectations	1	2	3	4	5	1.22

6. What were the most worthwhile parts of this program?
   - Group discussions – peer exchanges.
   - Interactive program. The participants were able to share their expertise and make a difference in the future direction of this study.
   - How to implement IC.
   - Discussion.
   - Finding out other DOT's experience and plans for IC.
   - Interactive discussion. In particular, the feedback from PennDOT on project experience. It was this that helped feed the conversation.
   - Open discussions of issues facing state DOTs.
   - Data discussion. Calibration to modulus/resilient modulus.
   - The new technology that is introduced.

7. What were the least worthwhile parts of this program?
   - Facilities.
   - N/A.
   - All good.
   - Everything good.
   - N/A.

8. What other topics were you hoping would be included in today's program?
   - How to get industry buy in.
   - All was covered.

9. Do you have any suggestions for future workshop topics?
   - How to best calibrate equipment.
   - A better platform, in my opinion, would have been to invite the contractors, manufacturers, and industry representatives, to have a more uniform participation of all experts in the field.
   - Discussion of existing IC specs in other jurisdictions.
   - More discussion on data management/analytics.
   - Best practices.
   - No.