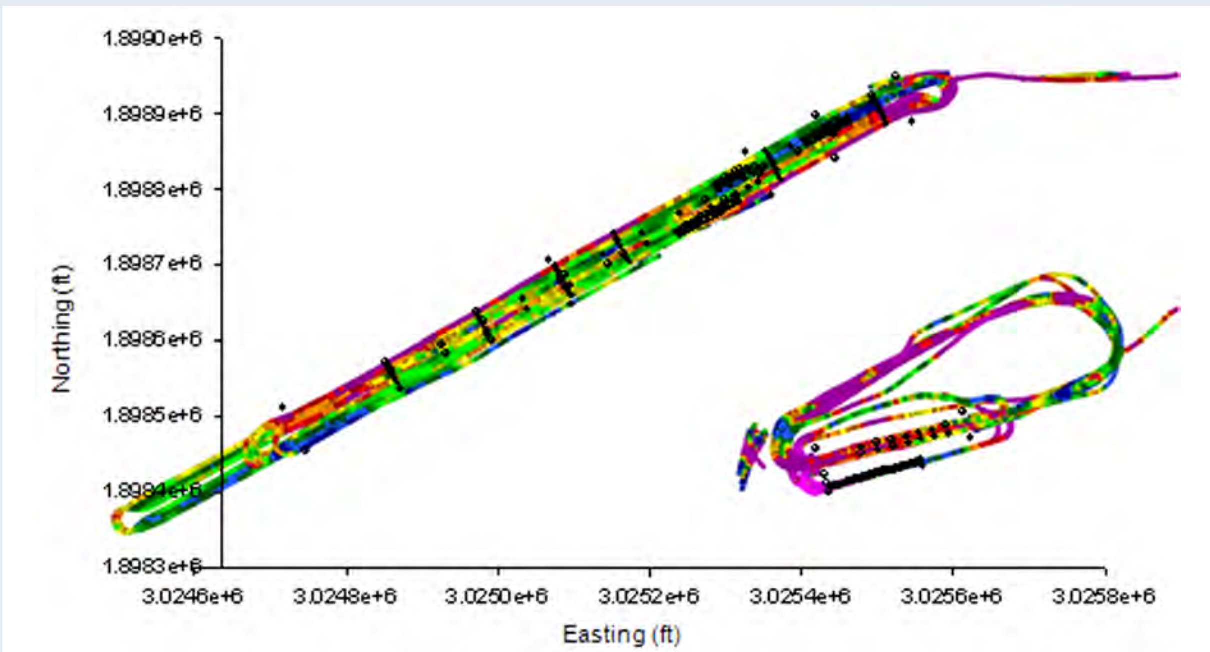
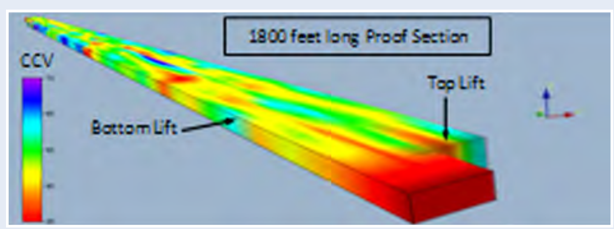
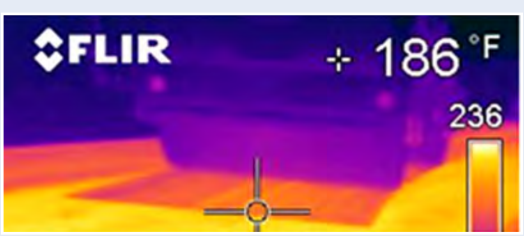
Report of the 1st Workshop for Technology Transfer for Intelligent Compaction Consortium

December 14–15, 2010







IOWA STATE UNIVERSITY
Institute for Transportation

Iowa Department of Transportation

Report of the 1st Workshop for Technology Transfer for Intelligent Compaction Consortium (TTICC)

Transportation Pooled Fund Study Number TPF-5(233)

December 14-15, 2010

David J. White, Ph.D.
Associate Professor
Department of Civil, Construction, and Environmental Engineering
2711 South Loop Drive, Suite 4700
Ames, Iowa 50010
515-294-1892
djwhite@iastate.edu

Pavana KR. Vennapusa, Ph.D.
Research Assistant Professor
Department of Civil, Construction, and Environmental Engineering
2711 South Loop Drive, Suite 4700
Ames, Iowa 50010
515-294-2395
pavanv@iastate.edu

Participating States: California, Georgia, Iowa, Kentucky, Mississippi, Missouri, Ohio, Pennsylvania, Utah, Virginia, and Wisconsin

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Preface

This document summarizes the discussion and findings of the 2010 workshop held on December 14-15, 2010 in Des Moines, Iowa, 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 DOT, Georgia DOT, Iowa DOT, Kentucky DOT, Missouri DOT, Mississippi DOT, Ohio DOT, Pennsylvania DOT, Utah DOT, Virginia DOT, and Wisconsin DOT.

The workshop was co-hosted by the Iowa DOT and 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 previous workshops, technical presentations, a discussion on current and developmental specifications, voting and brain-storming sessions on intelligent compaction road map research and implementation needs, and a discussion on future meetings. About 20 attendees representing the state DOTs participating in this pooled fund study, Federal Highway Administration, and researchers from Iowa State University and the University of Kentucky participated in this workshop.

Acknowledgments

Iowa State University of Science and Technology gratefully acknowledges the Iowa Department of Transportation (DOT) for hosting the workshop and the support of the following participating state agencies: California DOT, Georgia DOT, Iowa DOT, Kentucky DOT, Missouri DOT, Mississippi DOT, Ohio DOT, Pennsylvania DOT, Utah DOT, Virginia DOT, and Wisconsin DOT. Sharon Prochnow provided administrative support in organizing and executing the workshop. Iowa State University also sincerely thanks the following individuals for their support of this workshop:

Planning Committee

Sandra Larson, Iowa DOT

Mark Dunn, Iowa DOT

Steve Megivern, Iowa DOT

David White, Iowa State University

Pavana Vennapusa, Iowa State University

Heath Gieselman, Iowa State University

Presenters/Facilitators

Sandra Larson, Iowa DOT

Mark Dunn, Iowa DOT

David White, Iowa State University

Pavana Vennapusa, Iowa State University

Heath Gieselman, Iowa State University

Jonathan Fisher, University of Kentucky

Kean Ashurst, University of Kentucky

Mellissa Serio, Iowa DOT

Other Workshop Participants

California DOT—James Lee

Georgia DOT—Ian Rish, Alfred Casteel

Iowa DOT—Stephen Megiven, Jeffrey Schmidt

Missouri DOT—William Stone

Ohio DOT—Peter Narsavage

Utah DOT—Brent Gaschler

Virginia DOT—Edward Hoppe

Wisconsin DOT—Barry Paye

FHWA—Lisa Rold

Executive Summary

On December 14¬–15, 2010, the Iowa Department of Transportation (Iowa DOT) and Iowa State University co-hosted a 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 objective of the 2010 workshop was to generate a focused discussion to identify the research, education, and implementation goals necessary for advancing IC for earthworks and asphalt.

To develop these goals, the workshop's 20 attendees—representing the Federal Highway Administration (FHWA), Iowa State University and the University of Kentucky, and the 11 state DOTs participating in the study—reviewed previous workshops, attended technical presentations, discussed specifications, voted and brain-stormed about IC research, and discussed future meetings.

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 developed in 2009 and 2010 workshops. Though a new element was added and descriptions of exiting elements were modified, the top two IC research needs remained (1) developing and providing evidence of correlations between IC or continuous compaction control (CCC) measurements and in situ test measurements and (2) developing IC/CCC specifications and guidance. The revised IC road map is presented in Table 1.

Table 1. Prioritized IC road map of technology research/implementation needs

Prioritized IC/CCC Technology Research/Implementation Needs
1. Intelligent Compaction and In situ Correlations (24*)
2. Intelligent Compaction Specifications/Guidance (19*)
3. Data Management and analysis (8*)
4. Project Scale Demonstrations and Case Histories (7*)
5. Education/Certifications Programs (4*)
6. Understanding Impact of Non-Uniformity on Performance (4*)
7. Standardization of Roller Outputs and Format Files (4*)
8. IC Compaction Research Database (3*)
9. In Situ Testing Advancements and New Mechanistic Based QC/QA (2*)
10. Understanding Roller Measurement Influence Depth (1*)
11. IC Technology Advancements and Innovations (1*)
12. Sustainability** (1*)
13. Standardization of Roller Sensor Calibration Protocols (0*)

*total votes are provided in parenthesis
**newly added roadmap element

Other important outcomes from the 2010 TTICC workshop included providing a forum to facilitate information exchange and collaboration, developing a list of key products that need to be developed as part of the TTICC project, and developing plans for further TTICC meetings and other events.

Table 2 presents a list of products/items to be developed as part of the TTICC study, and Table 3 presents an action plan that the TTICC team can use to help advance IC/CCC technologies into earthworks and hot-mix asphalt (HMA) construction practice.

Table 2. List of products/items to be developed for the TTICC project

List of Products/Items to be developed for TTICC project

- **Develop at least 20 IC briefs based on existing field demonstration projects/research reports in the US. Develop one IC brief a month.**
- **Update EERC's TTICC website regularly and include all IC briefs with videos, and updated information related to TTICC project activities and workshop findings.**
- **Develop a Technology Overview Presentation for executive level officials in DOT.**
- **Explore funding opportunities for writing synthesis documents explaining IC technologies, QC/QA correlations, etc.**

Table 3. Action plan for advancing IC technologies into earthwork and HMA practices

Action Plan for Advancing IC/CCC Technologies into Earthwork and HMA

- **Develop case study information on different QC devices/correlations/ methods and strategies of data analysis.**
- **Compile a data base to evaluate correlations of in situ measurements to IC measurement values and evaluate in situ measurement tools.**
- **Develop Technology Independent Guide Specifications (FHWA/industry/ manufacturer/contractors/stage agencies review)**
- **Develop data analysis software by involving computer programmers.**
- **Conduct demonstration projects and open houses. Work with interested contractors in the state to get their buy-in and implement IC on pilot projects.**
- **Conduct a survey among different states in the US and European countries to learn from their experiences.**
- **Work toward development of NHI course and certification for operators, inspectors and engineers.**
- **Submit problem statements to TRB/NCHRP to create funding opportunities.**

Introduction

Technology Transfer Intelligent Compaction Consortium (TTICC)

Increasingly, state departments of transportation (DOTs) are challenged to design and build longer life pavements 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, 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 EERC hosted three workshops on Intelligent Compaction for Soils and HMA since 2008[1, 2, 3] and developed a roadmap to address the research, implementation, and educational needs to integrate 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 intelligent compaction (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, Mississippi DOT, Ohio DOT, Pennsylvania DOT, Utah 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 HMA
- Provide a forum for technology exchange between participants
- Develop and fund technology transfer materials
- Provide ongoing communication of research needs faced by state agencies to FHWA, states, industry, and the EERC

The 2010 TTICC Workshop was held on December 14-15, 2010 in Des Moines, Iowa. The workshop was attended by a total of 14 representatives from state DOTs, one representative from Federal Highway Administration (FHWA), four representatives from Iowa State University, and two representatives from the University of Kentucky.

[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 December 2010

Workshop Objectives and Agenda

The following were the key objectives of this workshop:

- Facilitate a collaborative exchange of information that accelerates effective implementation of IC technologies.
- Discuss TTICC project deliverables.
- Review current state DOT and current IC specifications for earthworks and HMA.
- Update the IC roadmap for identifying key research/implementation needs.
- Plan future meetings.

The workshop was held for 1½ days. The first day involved participant introductions with a brief review of their technical focus and job responsibilities; overview of TTICC project goals, objectives, and deliverables; review of past IC workshops and road map; overview of current IC specifications and review of developmental IC specification concepts; overview of current state earthworks and HMA specifications; presentations on current happenings and recent demonstration projects with IC; review of technology transfer products, IC brief templates, and TTICC website; review of IC road map; and breakout sessions on IC research, implementation, and educational needs. The second day involved breakout session summary reporting; discussion on future meeting plans and strategies to involve other state DOTs; and a brainstorming session with group exercise.

This report contains technical presentation slides and several documents that were provided to workshop participants, a log of questions/comments/discussions during presentations, results of breakout sessions and group exercise, prioritized IC implementation road map and workshop outcomes/proposed action items. The complete workshop agenda is included in Appendix A, and a list of attendees is provided in Appendix B. Photos of the workshop and comments evaluating the workshop are included in Appendices C and D, respectively. A brochure on the Geotechnical Mobile Lab is provided in Appendix E.

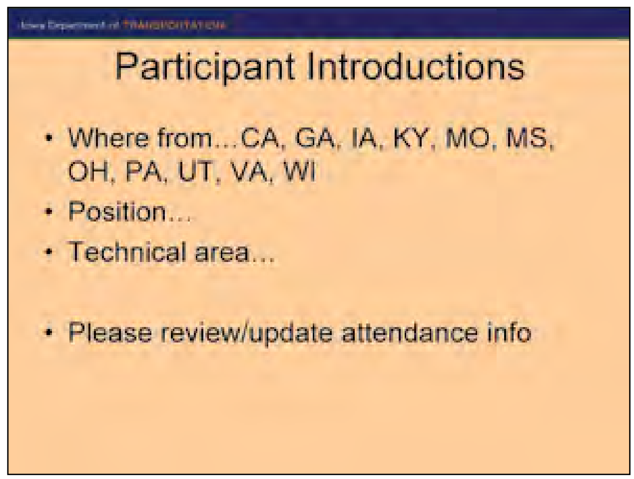
Presentations

The following is a list of the presentations delivered at the workshop. The presentation slides are provided on the following pages.

1. Introduction and Welcome—Sandra Larson
2. TTICC Goals, Objectives, Deliverables, and Agenda Review—Mark Dunn
3. Workshop Reviews 2008 to 2010—David White
4. Current Happenings in IC—David White, Pavana Vennapusa, and Heath Gieselman
5. Specification Review—David White, Pavana Vennapusa, and Heath Gieselman
6. Technology Transfer, Case History Template, and Website—David White
7. Breakout Session Results—Jonathan Fisher and Kean Ashurst
8. QC/QA Devices Impact on IC Implementation—Heath Gieselman

Introduction and Welcome

Sandra Larson



TTICC Goals, Objectives, Deliverables, and Agenda Review

Mark Dunn

Iowa Department of Transportation

TTICC Goals

- Identify needed research projects to advance IC
- Develop pooled fund initiatives
- Plan and conduct annual workshop on IC for soils, aggregate base, and asphalt.
- Provide forum for technology exchange
- Develop and fund technology transfer materials
- Provide on-going communication of research needs faced by state agencies to the FHWA, states, and industry.

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TTICC Deliverables

1. Identify and guide the development and funding of technology transfer materials such as tech brief summaries and training materials from research results
2. Review the IC Road Map as updated annually and provide feedback to the FHWA, industry, states, and the EERC on those initiatives
3. Be a forum for states and researchers to share their experience with IC technologies

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TTICC Deliverables

4. Provide research ideas to funding agencies
5. Identify and instigate needed research projects
6. Include current activities and deliverables of the pooled fund on the TTICC website
7. Maintain pooled fund project website with current activities and deliverables
8. Develop pooled fund research projects for solutions to intelligent compaction issues
9. Act as a technology exchange forum for the participating entities

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TTICC Deliverables

10. Contribute to a technology transfer newsletter on intelligent compaction research activities every six months in cooperation with the EERC
11. Post minutes to the website following web meetings
12. Post a report following each in-person workshop to the website

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Agenda Review

Workshop Reviews 2008 to 2010

David White

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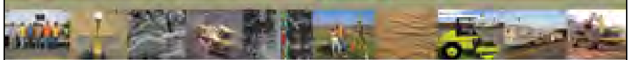

WORKSHOP REVIEWS 2008-2010:

INTELLIGENT COMPACTION FOR EARTHWORKS AND HMA

David J. White, Ph.D.
Associate Professor, Director, EERC

December 14-15, 2010

EERC
IOWA STATE UNIVERSITY
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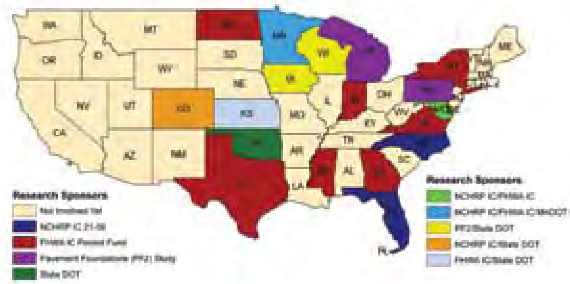
Iowa Department of Transportation

Dream it, Design it, Build it. www.ccee.engineering.iastate.edu

States Involved with IC Projects

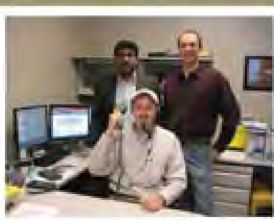


Previous Workshop Results: 2008, 2009

http://www.eerc.iastate.edu/publications.cfm

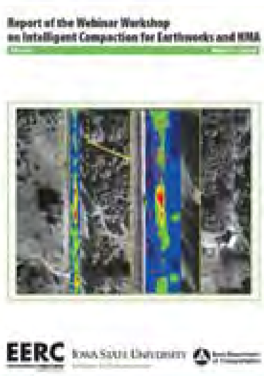
- 2.5 day events in Des Moines, IA
  - April 2-4, 2008
  - April 14-16, 2009
- ~100+ participants (State DOTs, FHWA, Contractors, Equipment Manufacturers, Academics)
- $$$ provided for State DOTs
- Technical Session, Breakout Working Sessions, Panel Discussion, Group Exercise
- Funded by Iowa DOT

Previous Workshop Results: 2010 Webinar



- State DOTs/FHWA: CT, GA, IA, IL, KS, MD, MI, MN, NC, ND, NJ, NY, OH, UT, VA, WA, and WI = 82 participants
- Contractors/Consultants: 18 participants
- Industry: 9 participants
- Trade Organizations: 2 participants
- Academia: 5 participants

http://www.eerc.iastate.edu/publications.cfm



2010 Workshop Goals/Opportunities

1. Provide a collaborative exchange of information that accelerates effective implementation of IC technologies.
2. Update roadmap for identifying key research and training focal areas (via email voting process).
3. **Establish collaborative task force with specific task and schedule to develop widely accepted and technology independent specifications.**

Workshop Reviews 2008 to 2010

David White

2010 Workshop Report – The Challenge

- Lack of adequate knowledge about technical aspects,
- No widely accepted specifications or standards,
- Limited number of well-documented case histories demonstrating the benefits of IC/CCC, and
- Inadequate education/training materials.

2010 IC Roadmap

Table 3. Prioritized IC technology research/implementation needs

Prioritized Top 10 IC Technology Research/Implementation Needs

1. Intelligent Compaction Specifications Guidance (41)
2. Intelligent Compaction and In Situ Correlations (25)
3. In Situ Testing Advancements and New Mechanistic-Based QC/QA (20)
4. Understanding Impact of Non-Uniformity of Performance (16)
5. Data Management and Analysis (18)
6. Project Scale Demonstration and Case Histories (15)
7. Understanding Roller Measurement Influence Depth (11)
8. Intelligent Compaction Technology Advancements and Innovations (9)
9. Education Program/Certification Program (8)
10. Intelligent Compaction Research Database (8)

2010 Key Outcomes

Table 7. Action plan for advancing IC technologies into earthwork and HMA practices

Action Plan for Advancing IC/CCC Technologies Into Earthwork and HMA

1. Establish a Technology Transfer Intelligent Compaction Consortium (TTICC) to identify research gaps and implementation needs, develop problem statements for needed research, identify key partners, and form a national-level Specifications Technical Working Group to coordinate efforts.
2. Explore the possibility of conducting a National Highway Institute course or a one-day training course at conferences on IC/CCC technologies.
3. Develop several case histories (technical briefs) to demonstrate the technical aspects and benefits of the technologies.
4. Plan future webinar workshop meetings to facilitate technology transfer.

2009 Specifications

Table 5. Summary of Specification Needs

Summary of Specification Needs

1. Different IC technologies exist and are evolving, so specifications should be technology independent.
2. Protocols for reporting, transfer, and evaluation of electronic data need to be developed.
3. QA measurement may need to move away from traditional density to mechanistic-based (e.g., strength, stiffness).

2009 Panel Discussion

Table 6. Summary of panel discussion

Key Outcomes from Panel Discussion

1. Need "champions" to create opportunities for implementation—using the technology for QC by contractor and perform independent QA by DOT is a good strategy to further implementation.
2. Need demonstration/pilot projects to improve confidence, create evidence that it reduces costs/improves efficiency to contractors, create training opportunities, and implement pilot specifications.
3. Need more research on identifying the "gold standard" QA method for correlations with IC measurements.
4. Need more refinement in the technologies with respect to more user-friendly onboard interfaces for data analysis and visualization and retrofitting capabilities.

IC Manufacturers Technology Updates - 2010

Table 4. Equipment manufacturers responses

Product overview

Description	Bomag	Case/Ammann	Caterpillar*	Dynapac	Sakai	Trimble	Volvo*
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
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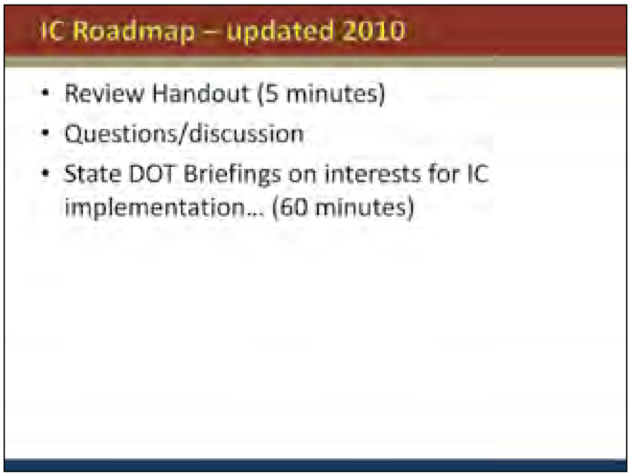
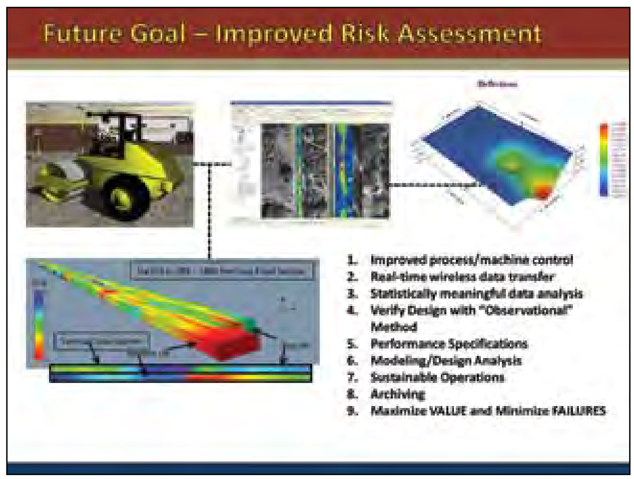
Workshop Reviews 2008 to 2010

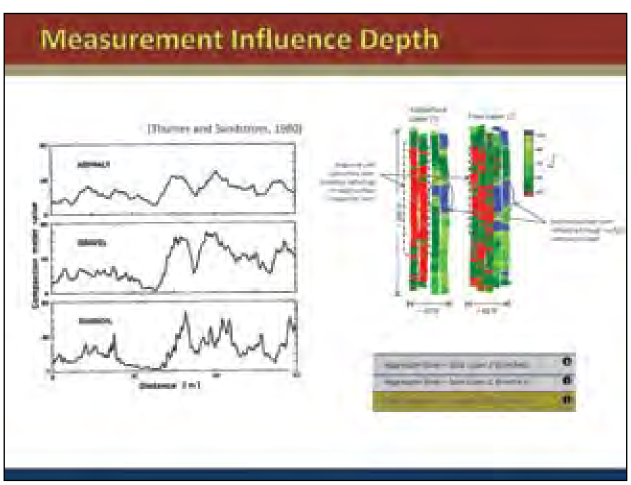
David White

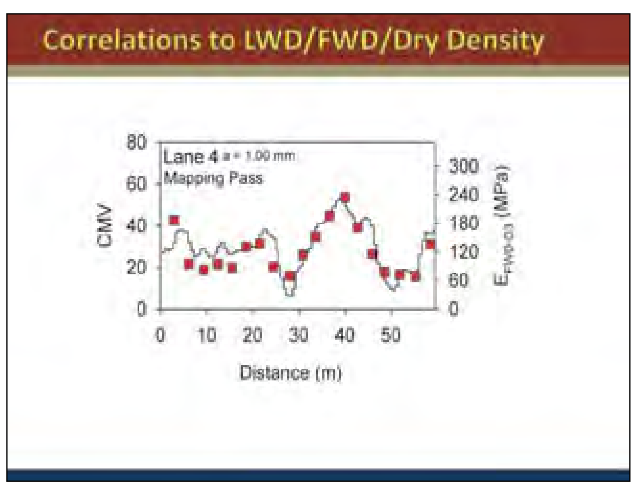


Current Happenings in IC

David White, Pavana Vennapusa and Heath Gieselman







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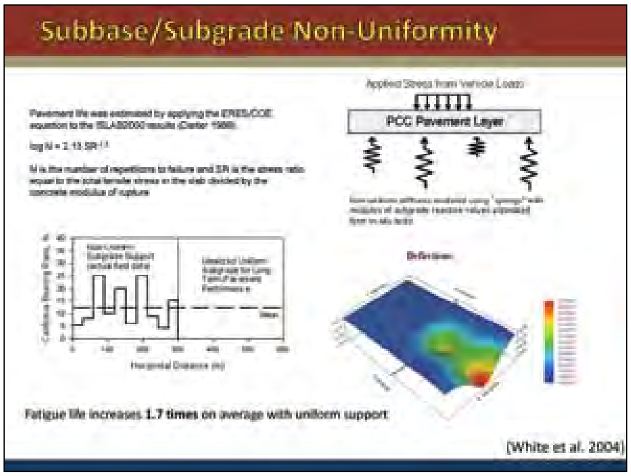

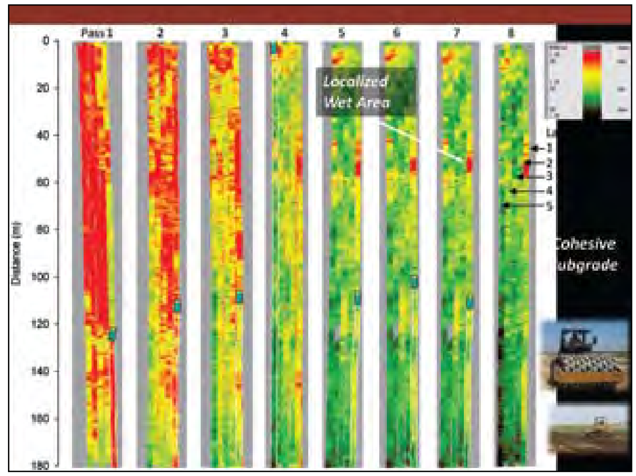

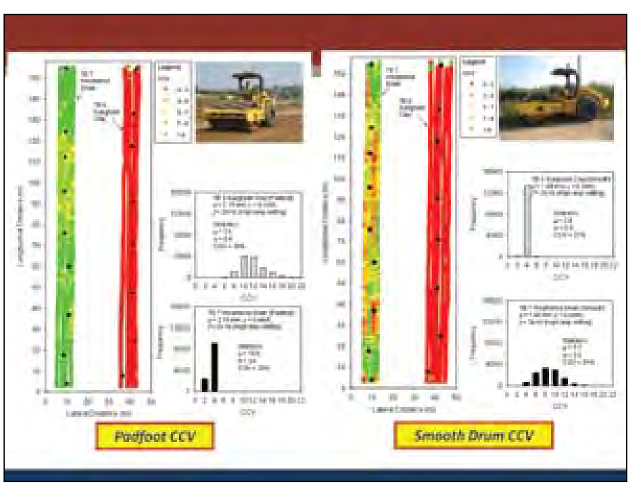

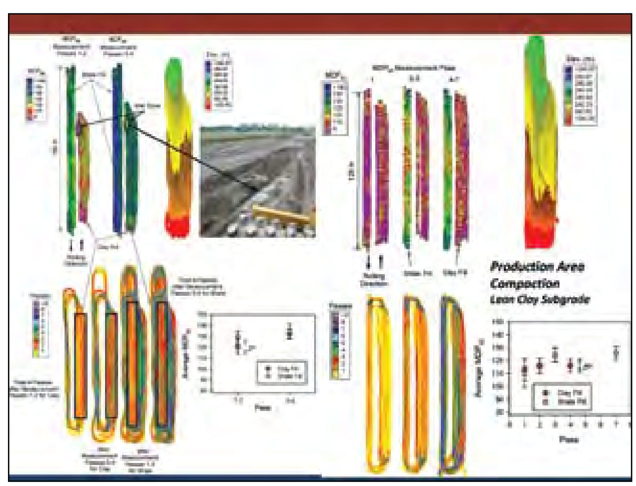

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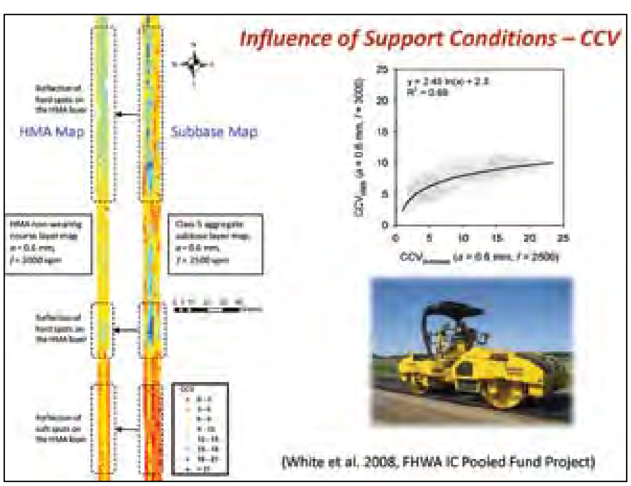

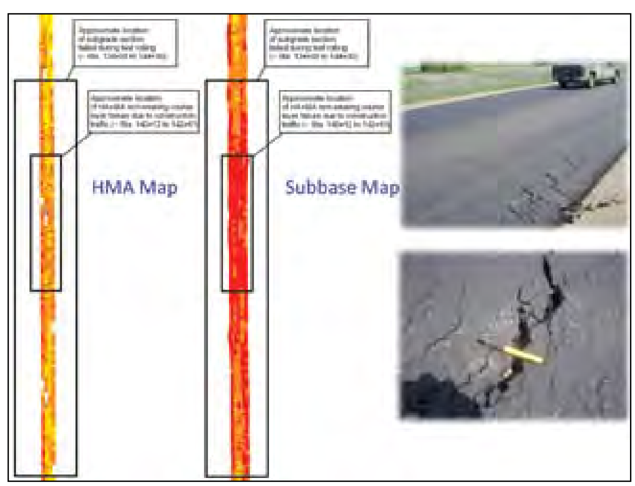

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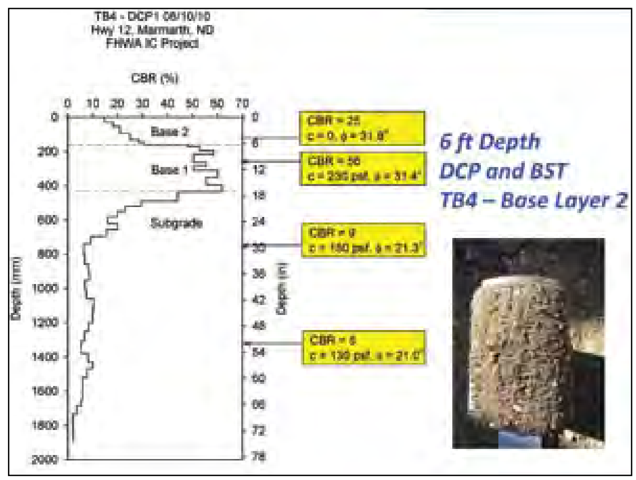

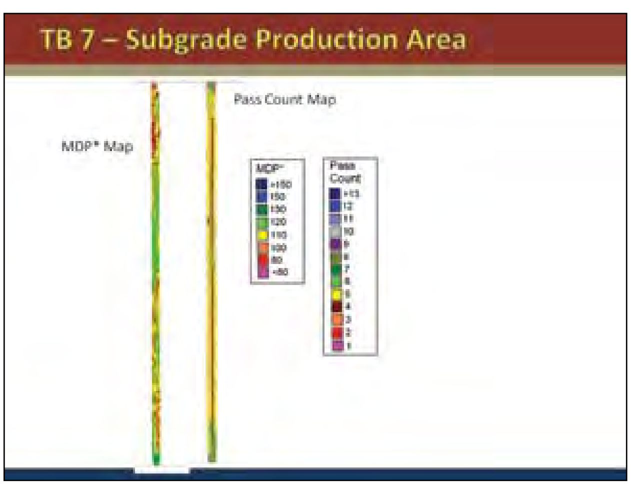

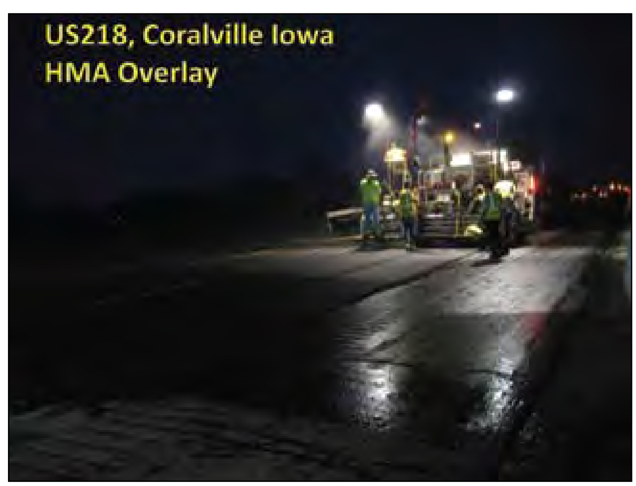

Current Happenings in IC

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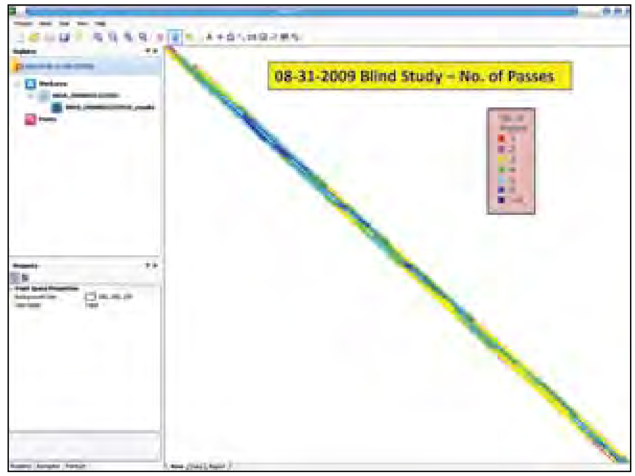

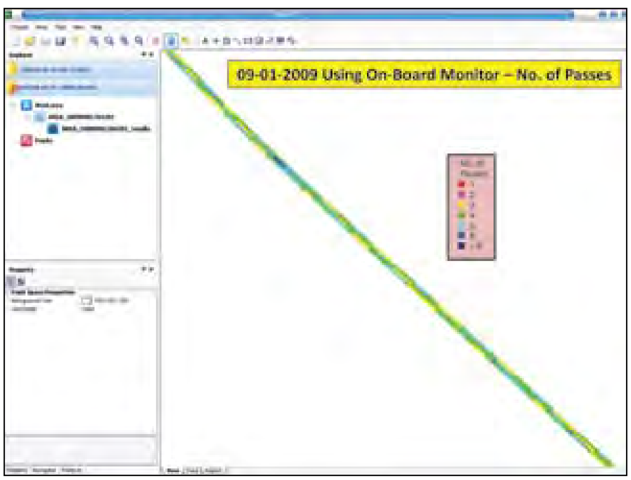

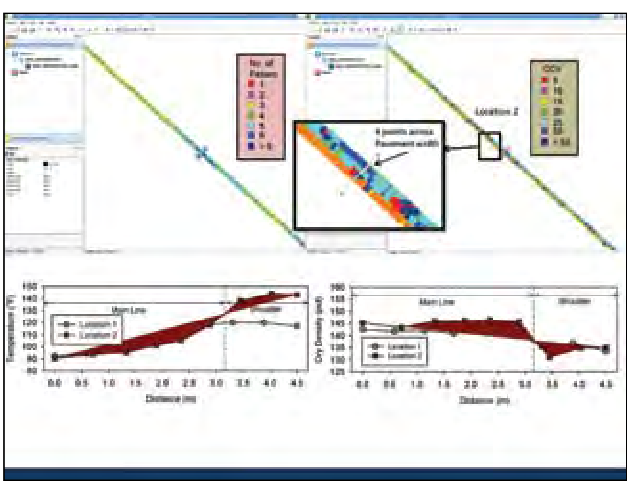

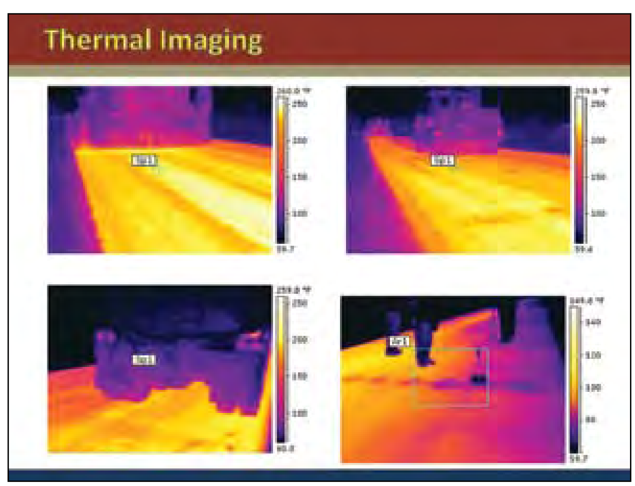

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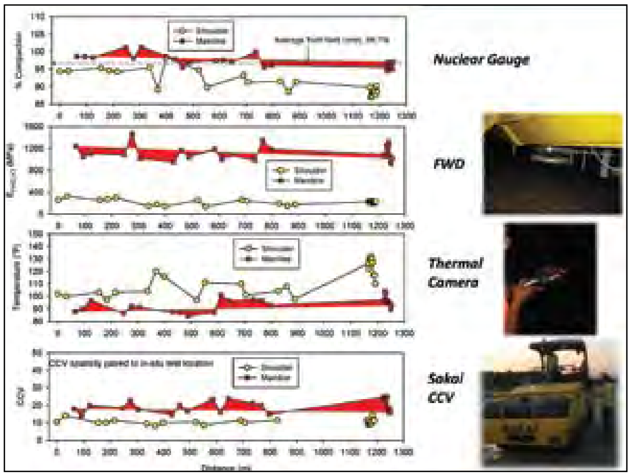
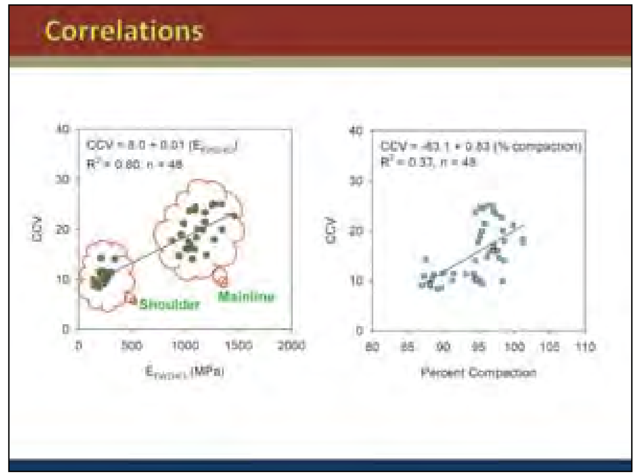
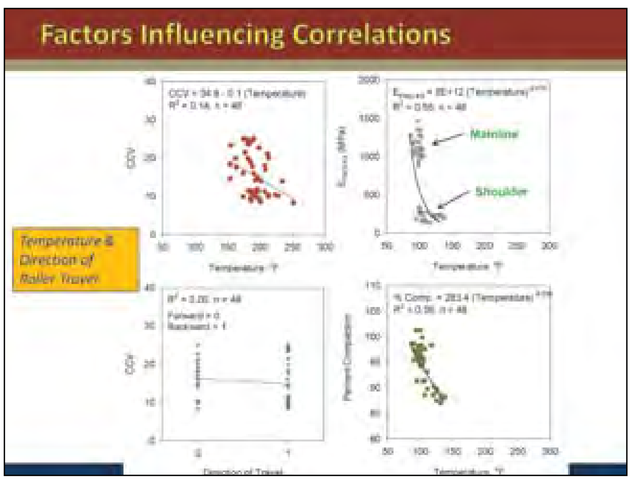
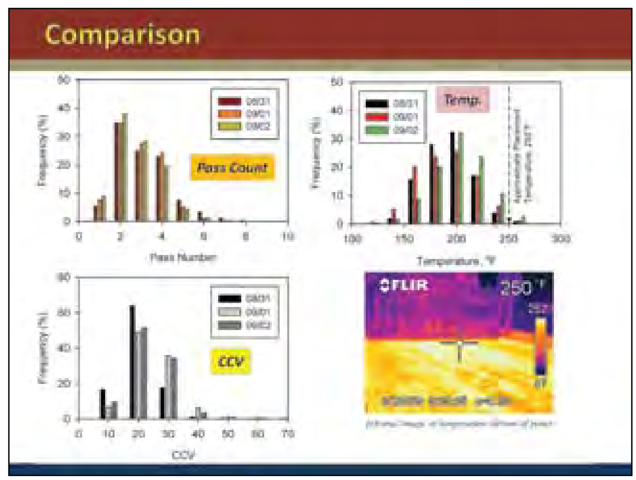
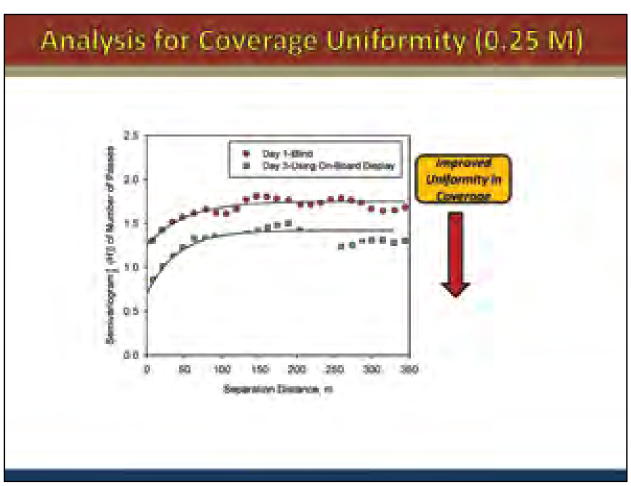




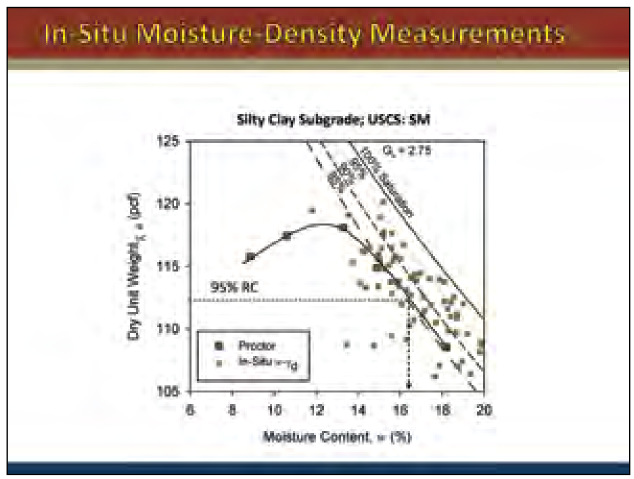


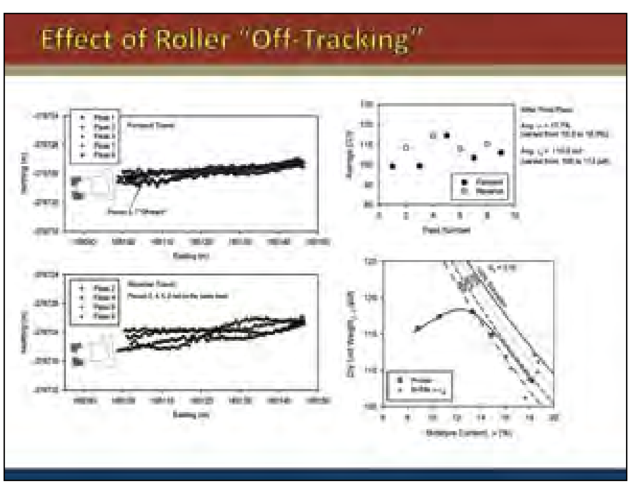


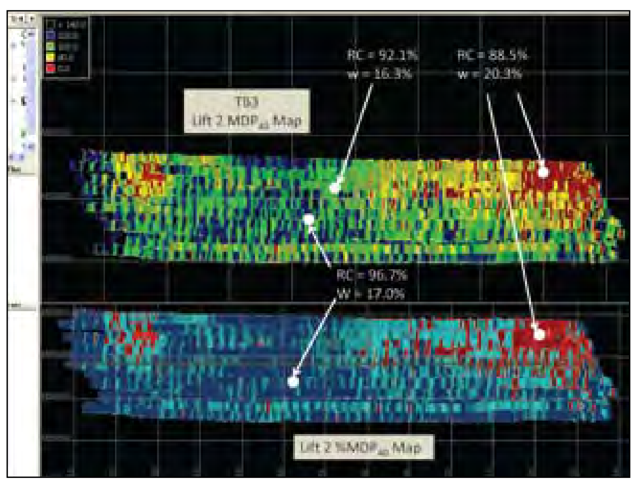


Current Happenings in IC

David White, Pavana Vennapusa and Heath Gieselman







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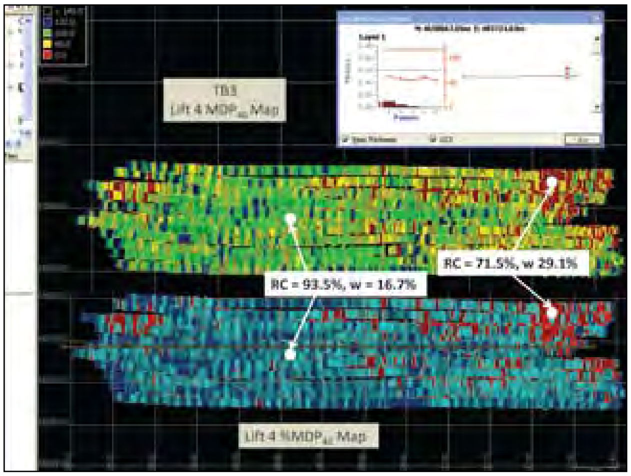

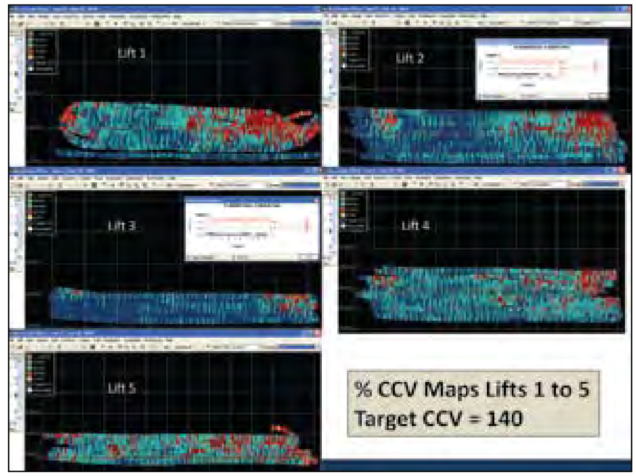

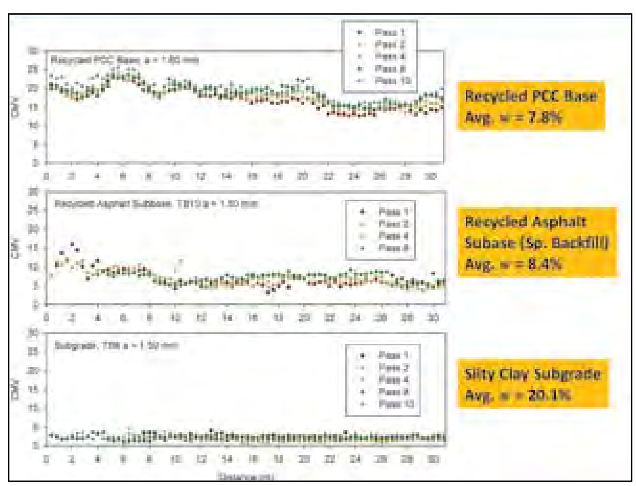

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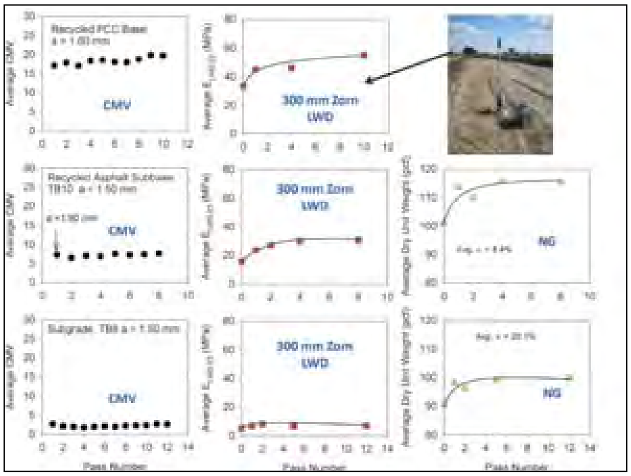

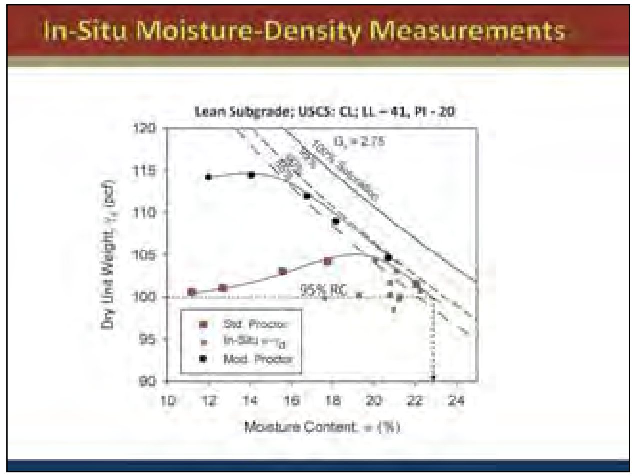

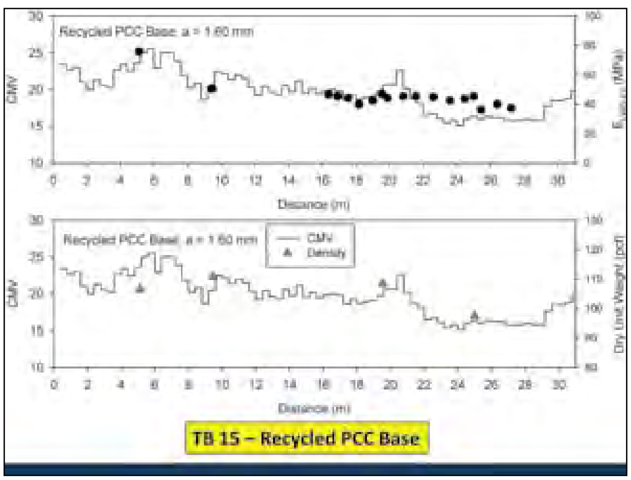

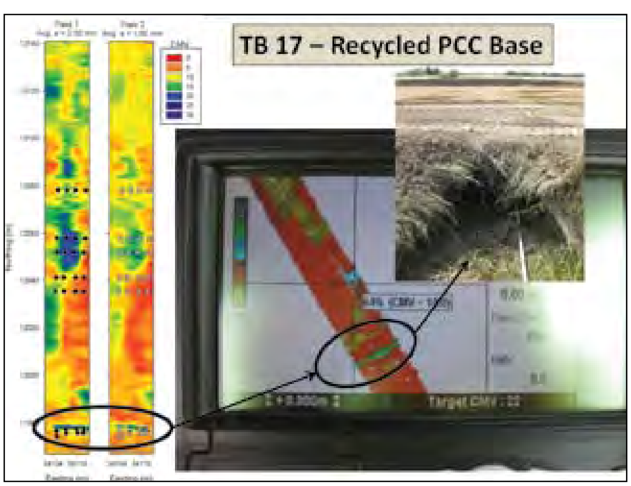

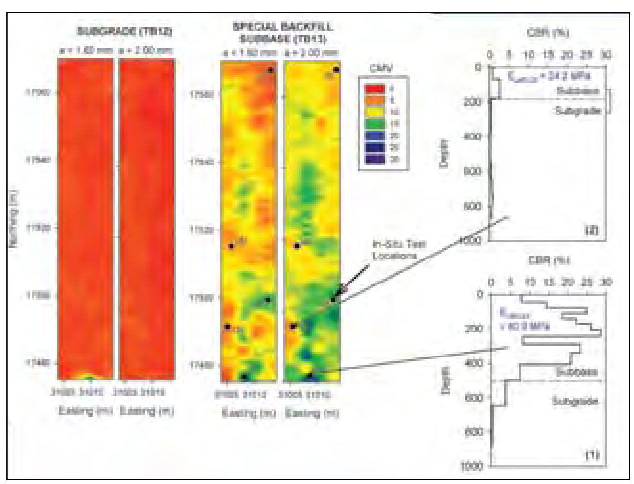

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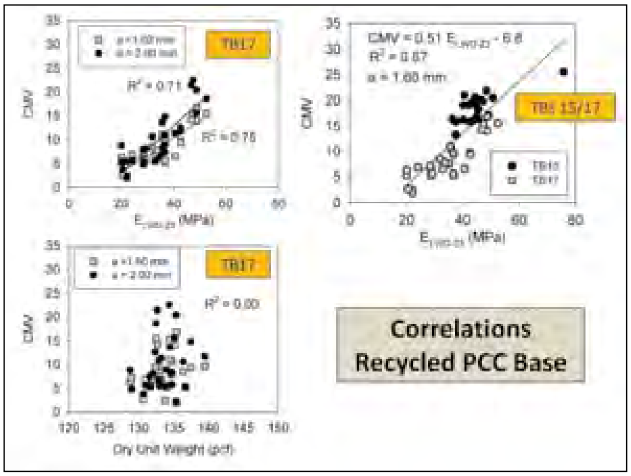

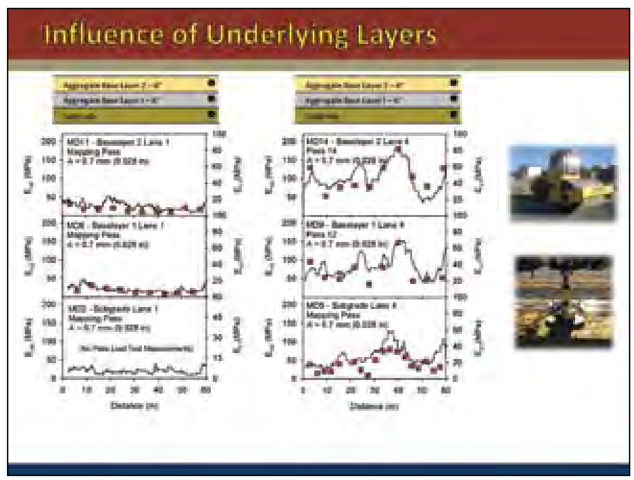

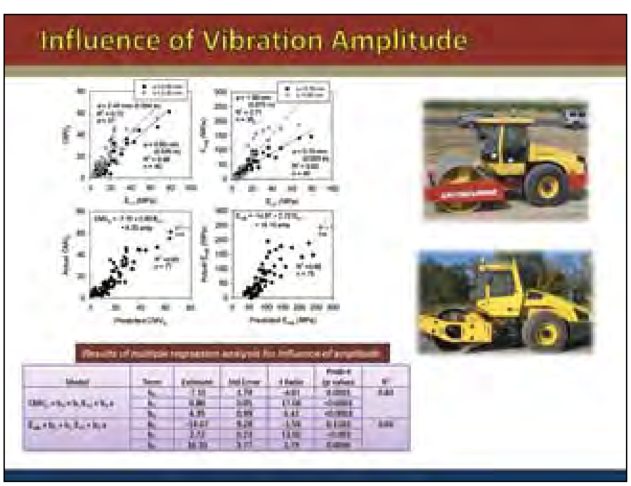

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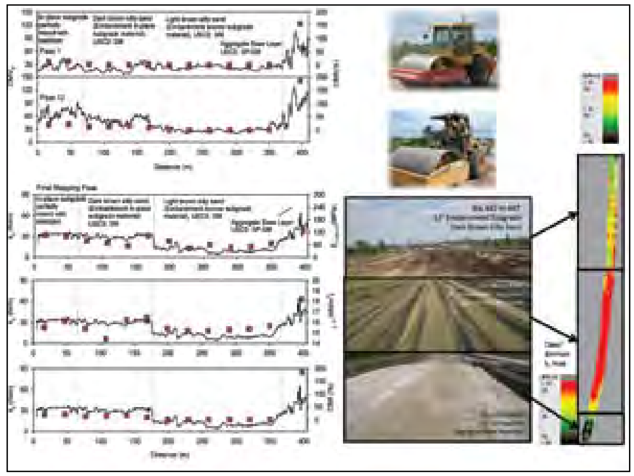

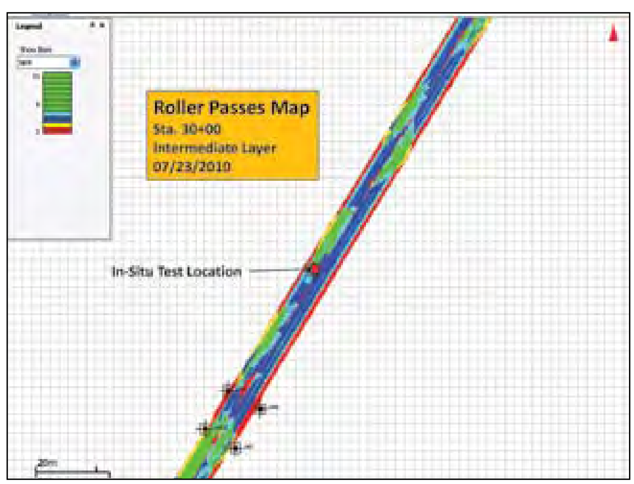

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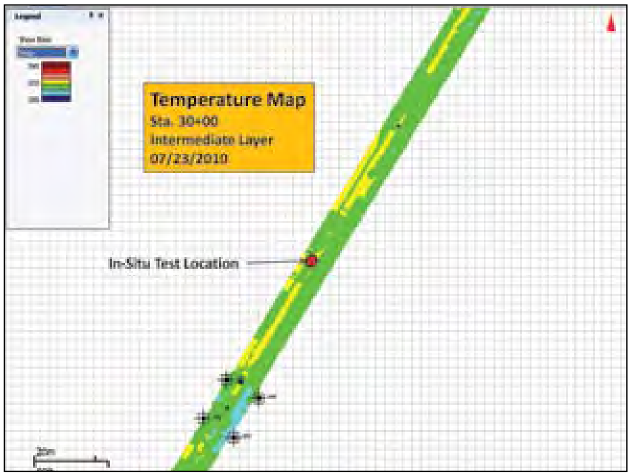
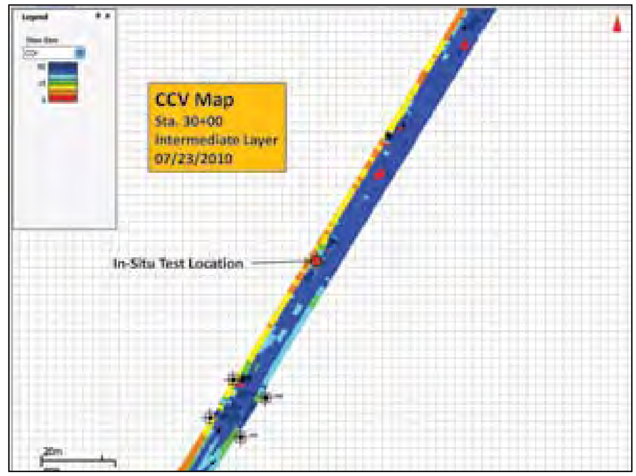
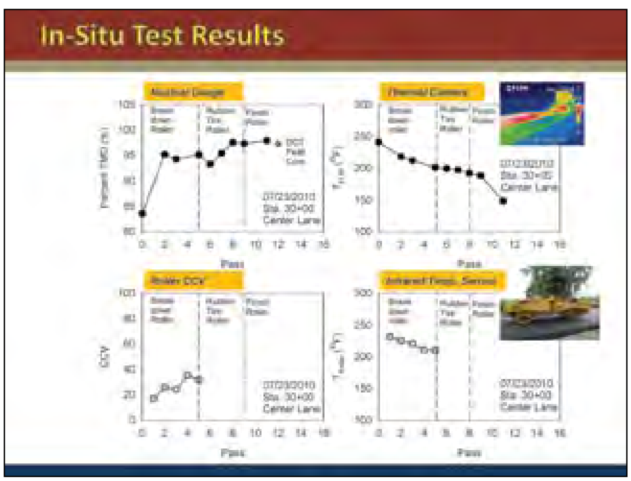
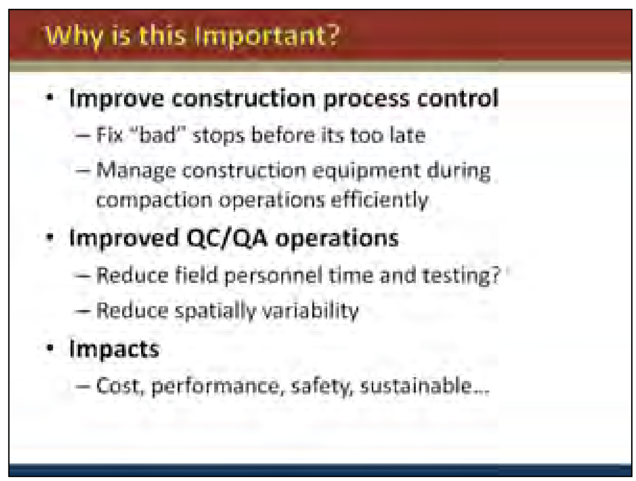


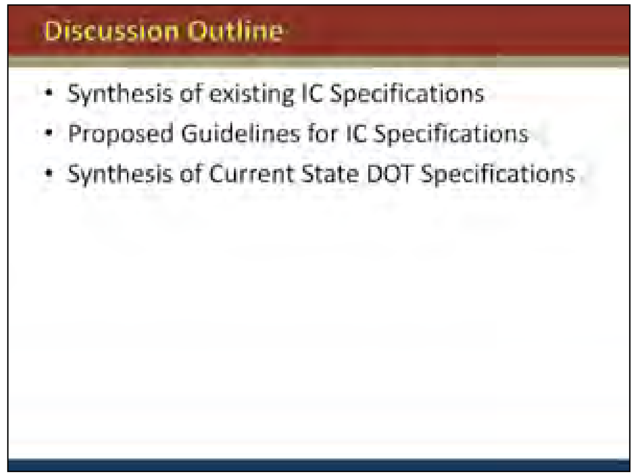


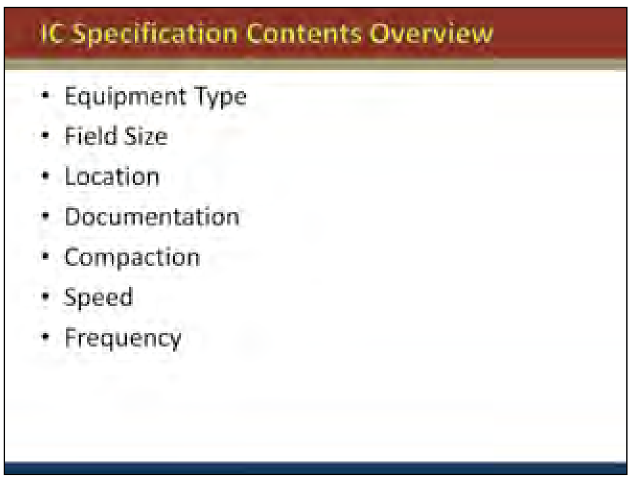


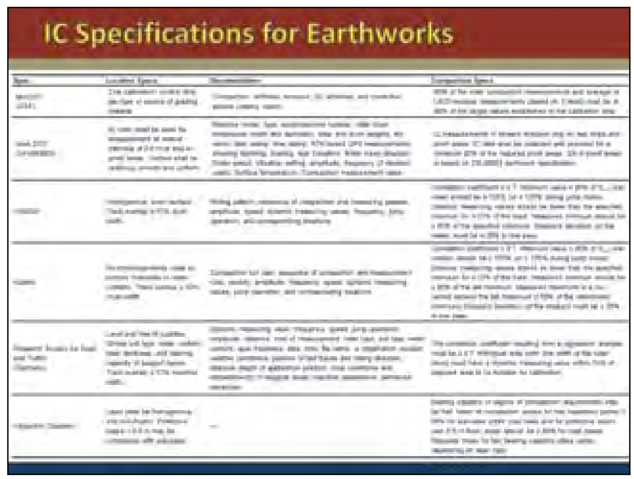


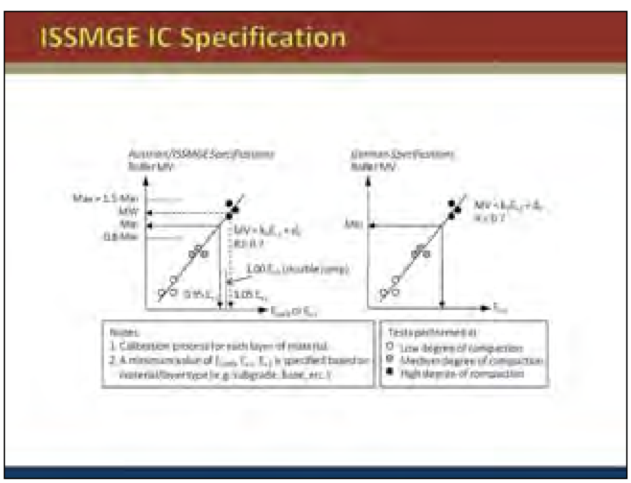
Specification Review

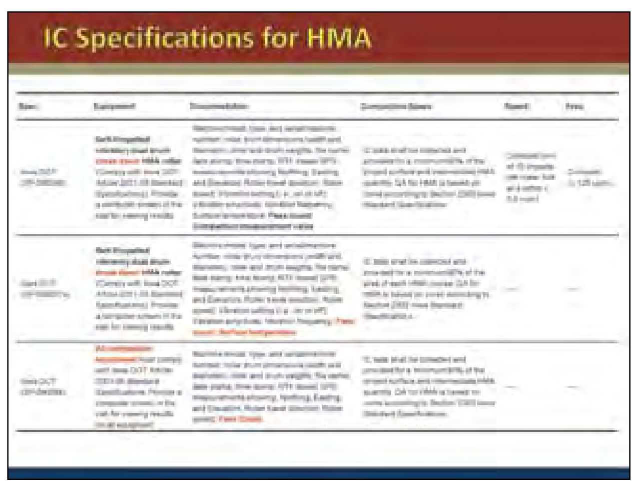
David White, Pavana Vennapusa and Heath Gieselman











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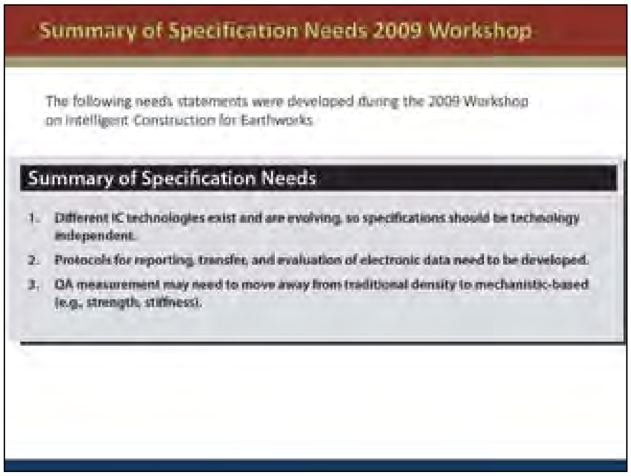
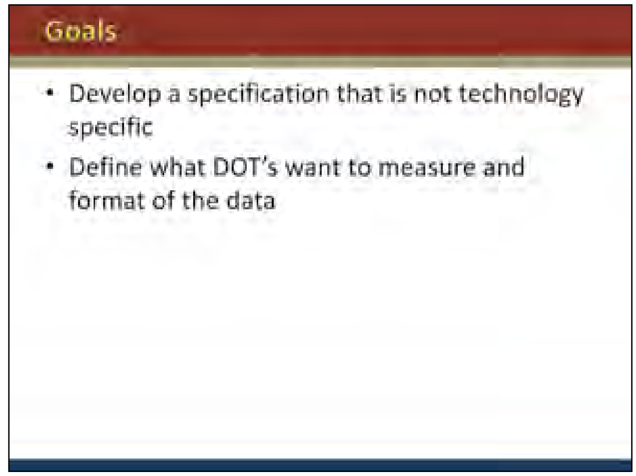
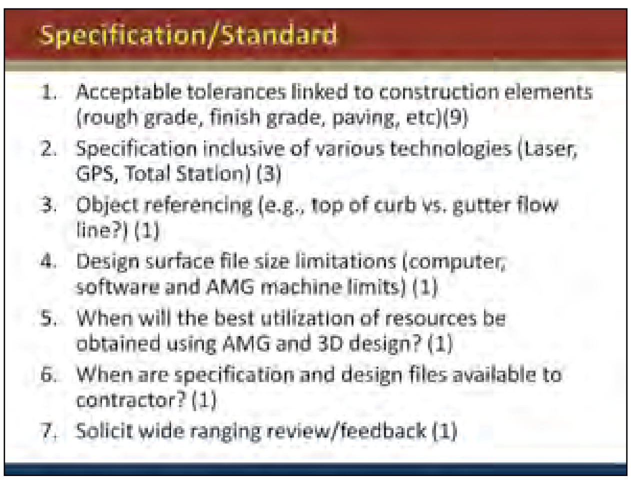
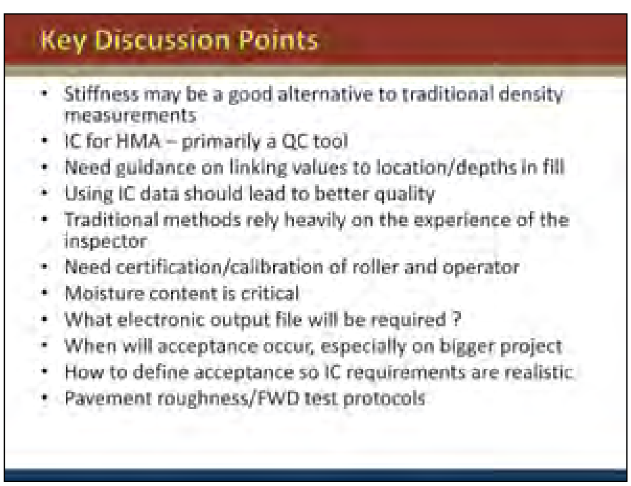


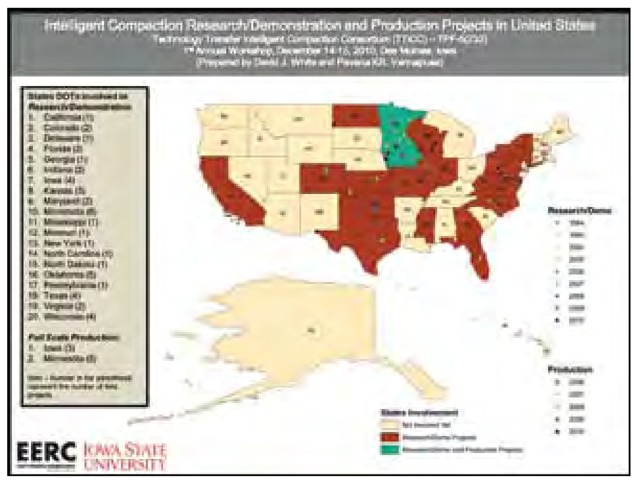




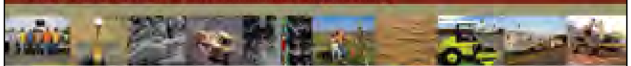


Technology Transfer, Case History Template, and Website

David White



IOWA STATE UNIVERSITY
Civil, Construction & Environmental Engineering



REPORT FROM BREAKOUT SESSIONS

Session # 1: Jonathan Fisher, Peter Narsavage, Melissa Serio, Edward Hoppe, Jeff Schmidt, William Stone, Mark Dunn, Ian Rish

Session # 2: Kean Ashurst, Stephen Megivern, Sandra Larson, James Lee, Alfred Casteel, Brent Gaschler, Barry Paye, David White

Facilitators: Pavana Vennapusa and Heath Gieselman

EERC

December 14-15, 2010

IOWA STATE UNIVERSITY Institute for Transportation

Iowa Department of Transportation

Dream it, Design it, Build it. www.ccee.engineering.iastate.edu

Session # 1 Report

By

Jonathan Fisher

Pavana Vennapusa

Session # 1 Report – Goals

- Identify research/implementation/educational needs using the 2010 IC Road Map
  - Brief discussion on all roadmap elements
  - Voting to prioritize roadmap rating
  - More discussion on TOP 3 prioritized elements
  - Identified ACTION items
- Discussion on future workshops

Session # 1 Report – Voting Results

Roadmap Element	Votes	Soil	Base	Asphalt	New Ranking
1. IC and In-situ Correlations	16	X	X	X	1
2. IC Specifications/Guidance	12	X	X	X	2
3. In Situ Testing Advancements and New Mechanistic Based QC/QA	0	X	X	X	7
4. IC Technology Advancements and Innovations	2	X	X	X	3
5. Project Scale Demos and Case Histories	1	X	X	X	4
6. Understanding the Impact of Non-Uniformity on Performance	1	X	X	X	6
7. Data Management and Analysis	2	X	X	X	5
8. Standardization of Roller Outputs and Format Files	[illegible]	X	X	X	3
9. Understanding Roller Measurement Influence Depth	0	X	X	X	
10. Education Program/Certification Program	0	X	X	X	
11. IC Research Database	0	X	X	X	
12. Standardization of Roller Sensor Calibration Protocols	0	X	X	X	

Session # 1 Report – Discussion

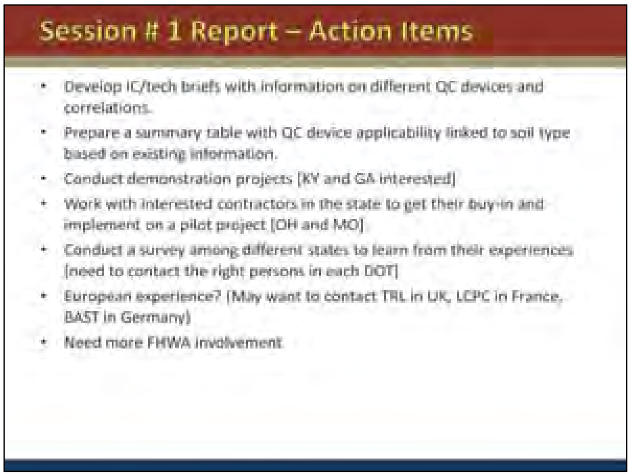
- **Suggestions/Additions/Discussion Items on TOP 3 Roadmap Elements:**
  - **(1) IC and In-Situ Correlations**
    - Define "gold" standard measurement
    - Correlations with traditional density measurements
    - Correlations with PQI for HMA
    - Correlations with FWD
    - Correlations on WMA
    - Future work on Roller Compacted Concrete
    - Which QC device produces better correlations (depending on soil type)?

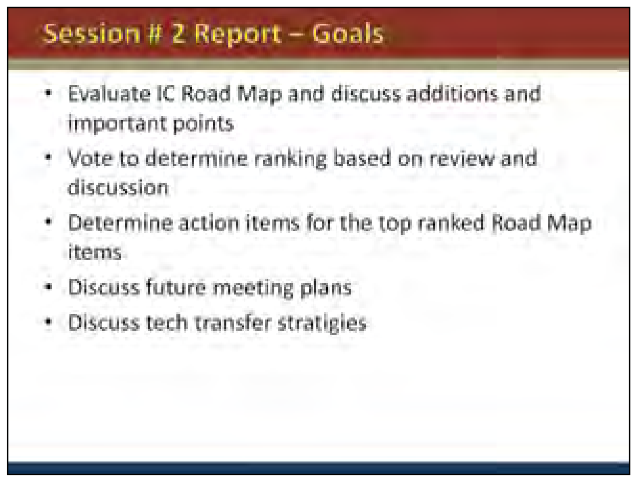
Session # 1 Report – Discussion

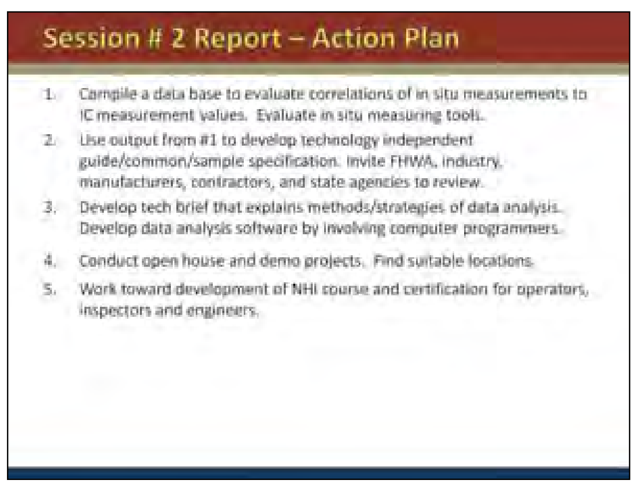
- **(2) IC Specifications and Guidance**
  - Likely to start using IC for QC only. Issues with using IC for QA.
  - Start with Pilot Projects with recording only Pass count/elevation information to get experience.
  - Need to develop a technology independent "umbrella" specification to use different QC devices and IC machines
  - Need to address "Equipment Specifications" for IC equipment
  - Need to address training/education in specs.
- **(3) Standardization of Roller Outputs and Format Files**
  - Develop database schema for data archival purposes.

Breakout Session Results

Jonathan Fisher and Kean Ashurst







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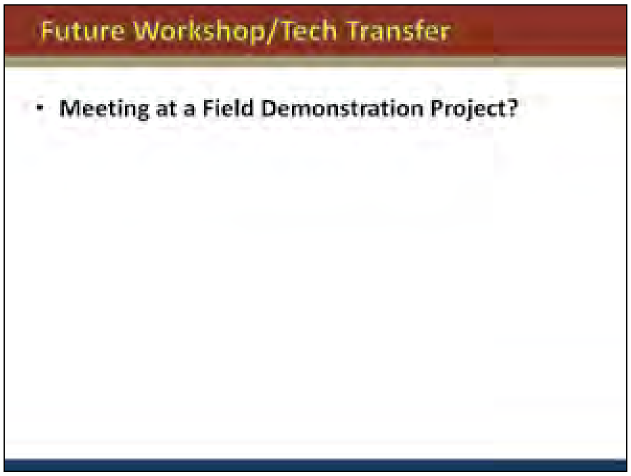
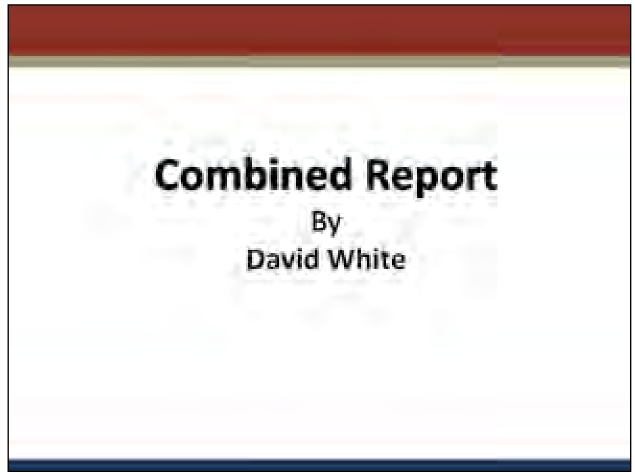
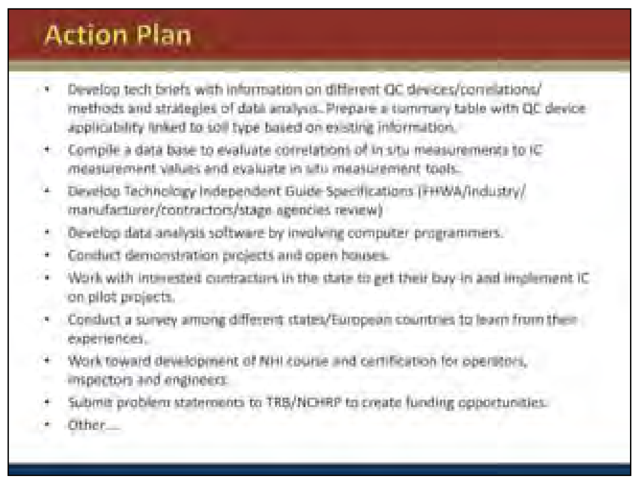
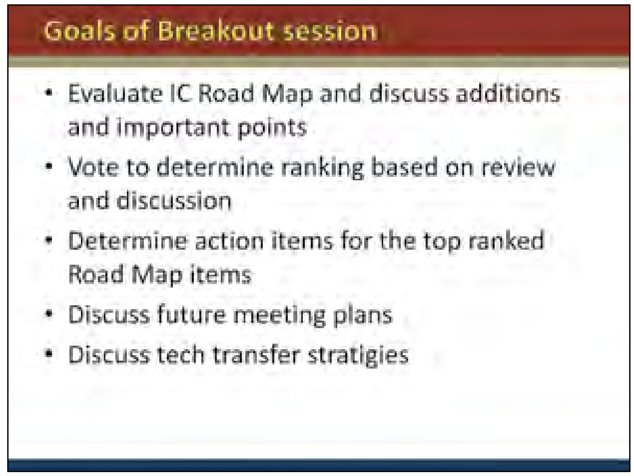


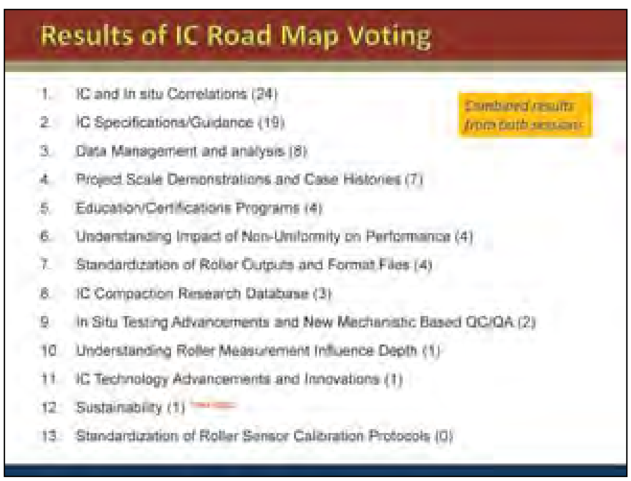


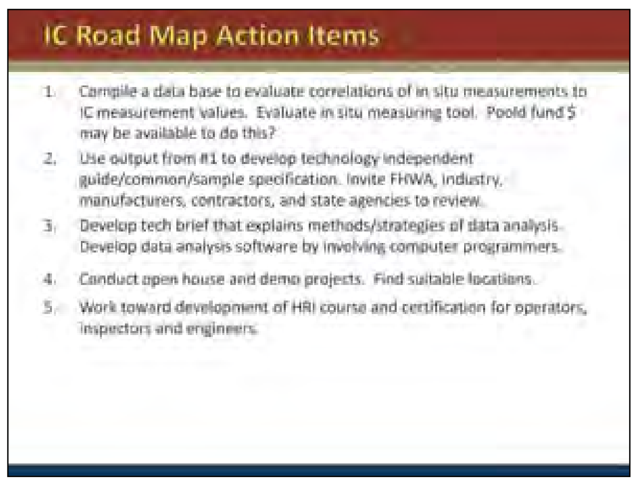


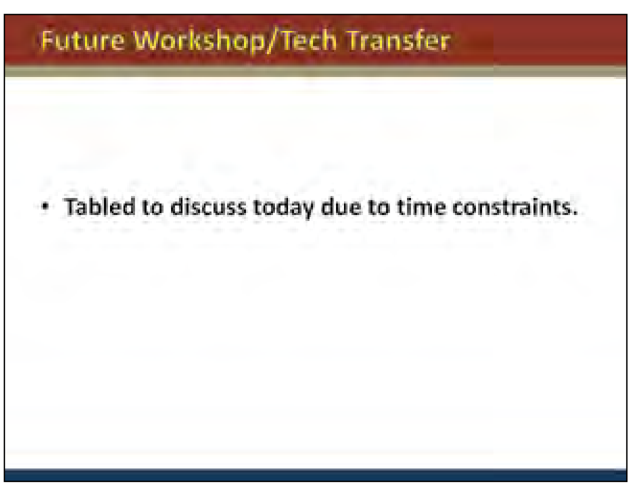
QC/QA Devices Impact on IC Implementation

Heath Gieselman









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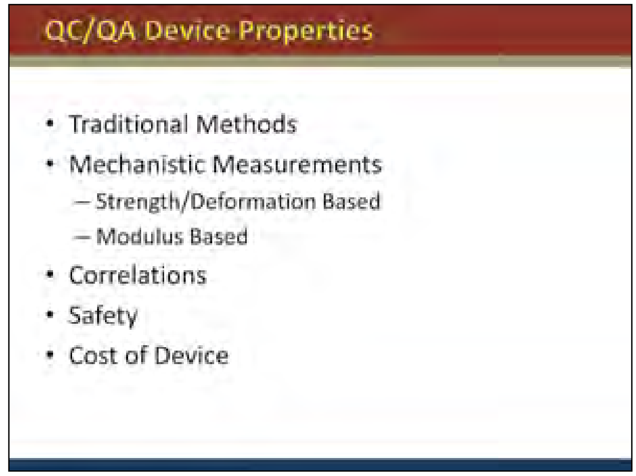
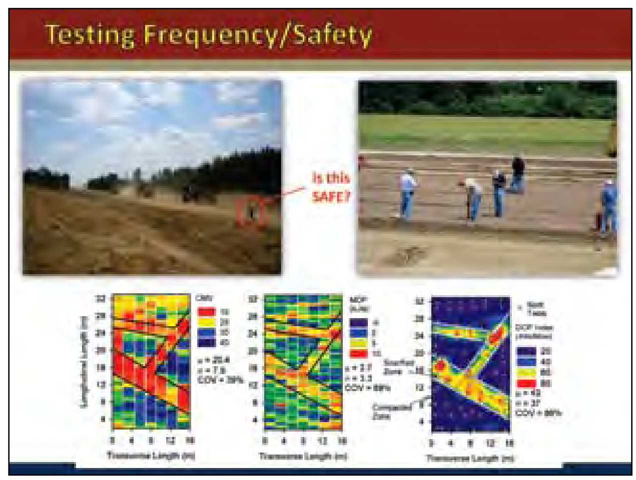




Workshop Products

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

1. TTICC Problem Statement
2. Summary of IC Specifications for Earthworks and HMA—David White and Pavana Vennapusa
3. Guidelines for IC Developmental Specifications—David White and Pavana Vennapusa
4. Results of 2009 IC Workshop Breakout Sessions on IC Specifications
5. Summary of Current Specifications [Draft]—Pavana Vennapusa and David White
6. IC Projects Map—David White and Pavana Vennapusa

1. TTICC Problem Statement

---------- DRAFT----------

TECHNOLOGY TRANSFER INTELLIGENT COMPACTION CONSORTIUM

Pooled Fund Project

Problem Statement
February, 2010

PROJECT TITLE

Establishment of a Technology Transfer Intelligent Compaction Consortium (TTICC) to identify, advise, and fund research and technology transfer for intelligent compaction technologies.

PROBLEM STATEMENT

Increasingly, state departments of transportation (DOTs) are challenged to design and build longer life pavements 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, Federal Highway Administration (FHWA), academia and industry must collaborate to identify and examine new and emerging technologies and systems. The purpose of this pooled fund project is to identify, support, facilitate and fund intelligent compaction research and technology transfer initiatives.

The Iowa DOT will serve as the lead state for the execution of the pooled fund project described in this proposal. The Iowa DOT, through the Earthworks Engineering Research Center (EERC) at Iowa State University, will handle all administrative duties associated with the project. The EERC will also serve as the lead research institution for the project.

PROJECT GOALS

The goal of the TTICC is to:

- Identify needed research projects
- Develop pooled fund initiatives
- Plan and conduct an annual workshop on intelligent compaction for soils and HMA.
- 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 EERC.

It is anticipated that this consortium would become the national forum for state involvement in the technical exchange needed for collaboration and new initiatives, and be a forum for advancing the application and benefit of intelligent compaction technologies for soils, bases, and asphalt pavement uses.

State participation in this process will be through the pooled fund. FHWA, industry and others will be invited to participate in the project discussions and activities.

BACKGROUND

1

In 2008 and 2009 the Iowa Department of Transportation and the EERC hosted an annual workshop on Intelligent Compaction for Soils and HMA. As part of the workshop a roadmap for addressing the research and educational needs for integrating intelligent compaction technologies into practice was developed. An ongoing forum is needed to provide broad national leadership that can rapidly address the needs and challenges facing STAs with the adoption of intelligent compaction technologies. The vision for the road map was to identify and prioritize action items that accelerate and effectively implement IC technologies into earthwork and HMA construction practices. Coupled with the IC technologies are advancements with in situ testing technologies, data analysis and analytical models to better understand performance of geotechnical systems supported by compacted fill, software and wireless data transfer, GPS and 3D digital plan integration, new specification development, and risk assessment. What follows in Table 1 is the road map with the 2008 and 2009 priority rankings. For information on the first two workshops please refer to the workshop reports at the EERC website: http://www.eerc.iastate.edu/publications.cfm

RESEARCH PLAN AND DELIVERABLES (PROJECT DESCRIPTION)

The proposed project is for the establishment of a pooled fund for state representatives to continue this collaborative effort regarding intelligent compaction. The TTICC will be open to any state desiring to be a part of new developments in intelligent compaction leading to the implementation of new technologies which will lead to longer life pavements through the use of an integrated system of emerging innovative technologies. Two workshop meetings will be conducted each year. One of the meetings will be in person and is anticipated to occur during fall. The location of the in-person workshop meetings will be determined by the Executive Committee and moved regionally each year to participating states. The second meeting will be a webinar and occur in early spring hosted by the EERC.

All efforts by the TTICC will be focused towards these project activities and deliverables:

- Identify and guide the development and funding of technology transfer materials such as tech brief summaries and training materials from research results
- Review the IC Road Map as updated annually and provide feedback to the FHWA, industry, states, and the EERC on those initiatives
- Be a forum for states and researchers to share their experience with IC technologies
- Provide research ideas to funding agencies
- Identify and instigate needed research projects
- Include current activities and deliverables of the pooled fund on the TTICC website
- Maintain pooled fund project website with current activities and deliverables
- Develop pooled fund research projects for solutions to intelligent compaction issues
- Act as a technology exchange forum for the participating entities
- Contribute to a technology transfer newsletter on intelligent compaction research activities every six months in cooperation with the EERC
- Post minutes to the website following web meetings
- Post a report following each in-person workshop to the website

EXECUTIVE COMMITTEE

An Executive Committee will be formed from the TTICC to review and approve the pooled fund activities and budget. The Executive Committee will meet at a schedule to be determined by the Executive Committee via conference calls.

RESEARCH TEAM

The project managers for the TTICC will be the EERC; lead by Dr. David White.

Dr. White is the director of the Earthworks Engineering Research Center (EERC) at Iowa State University. Dr. White's M.S. and Ph.D. research involved large-scale field testing to evaluate embankment construction methods and development of design and construction guidelines for stabilized subgrade. Since Dr. White's start as an assistant professor at Iowa State University in August 2001 he has been successful in directing research from a diverse group of organizations for a total of aggregate dollar total of over $10 million. Dr. White has ten years of experience with earthwork and pavement foundation layer improvement, ground systems, QC/QA testing, specification development, and six years of experience evaluating intelligent compaction systems. Dr. Pavana Vennapusa and Mr. Heath Gieselman will also contribute to the project and have extensive experience with intelligent compaction technologies.

This project will be conducted through the EERC. The EERC works with partners to bring about rapid advancements in quality, economy, and performance of the geotechnical aspects of civil infrastructure through a fundamental understanding of earth mechanics, and by providing enabling technologies and supportive public policies.

The EERC's main offices are located at the Institute for Transportation (InTrans) in the Iowa State University Research Park, roughly three miles from both the ISU campus and the Iowa DOT's headquarters in Ames, Iowa.

ESTIMATED PROJECT DURATION and COST

The pooled fund project duration is for five years. The annual cost of participation for one person is $7,000, which includes travel expenses and registration for the annual workshop and web-based meeting. Additional participants can be added for $2000/year.

The pooled fund sponsorship goal is participation from ten states.

SUMMARY OF PROJECT SPONSOR REQUIREMENTS

- Financial support
- Meeting participation twice a year, in person and via a webinar
- Active collaboration with each other and others to identify, support, facilitate and fund intelligent compaction research and technology transfer initiatives.
- Championing within their state the deliverables from the pooled fund, such as technical material to key staff, and facilitate implementation of new technologies and practices.

CONTACT FOR FURTHER INFORMATION

Lead State Contact

<u>Technical Contact</u>
Mr. Steve Megivern, P.E.
Soils Design Section
Iowa Dept. of Transportation
800 Lincoln Way

Ames, Iowa 50021
515-239-1936
515-239-1873 (f)
stephen.megivern@dot.iowa.gov

Administrative Contact

Ms. Sandra Q. Larson, P.E.
Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010
515-239-1205
515-239-1766 (f)
sandra.larson@dot.iowa.gov

EERC Contact

David J. White, Ph.D.
Associate Professor and holder of Wegner Professorship
Director, Earthworks Engineering Research Center
Department of Civil, Construction and Environmental Engineering
Iowa State University
Town Engineering Building RM 422,
Ames, Iowa 50011-3232
515.294.1463
515.290.1080 (c)
djwhite@iastate.edu

Table 1. Intelligent Compaction Road Map for Research and Training

IC Road Map Research and Educational Elements

1. **Intelligent Compaction Specifications/Guidance (4*).** 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.

2. **Intelligent Compaction and In-Situ Correlations (2*).** 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. A database and methods for establishing IC target values will be the outcome of this study. Information generated from this research element will contribute to research elements 1, 9, and 10.

3. **In-Situ Testing Advancements and New Mechanistic Based QC/QA (8*).** 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.

4. **Understanding Impact of Non-Uniformity of Performance (10*).** 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 research elements 1, 5, and 9.

5. **Data management and Analysis (9*).** 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 research elements 1, 2, 3, 6, 8, 9, and 10.

6. **Project Scale Demonstration and Case Histories (3*).** 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 research element 1, 9, and 10.

7. **Understanding Roller Measurement Influence Depth (6*).** 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.

8. **Intelligent Compaction Technology Advancements and Innovations (7*).** 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. It is envisioned that much of this research will be incremental and several sub-elements will need to be developed.

9. **Education Program/Certification Program (5*).** 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 than 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.

10. **Intelligent Compaction Research Database (1*).** 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 research element will contribute to research elements 1, 2, 6, 9.

***2008 Workshop Ranking**

2. Summary of IC Specifications for Earthworks and HMA — David White and Pavana Vennapusa

Summary of existing roller-integrated compaction monitoring technology earthwork specifications

Spec.	Equipment	Field Size	Location Specs	Documentation	Compaction Specs	Speed	Freq.
Mn/DOT (USA) [Earthwork]	Smooth drum or padfoot vibratory roller (25,000 lbs.)	100 m x 10 m (mini-mum at base). Max 1.2 m thick.	One calibration/ control strip per type or source of grading material	Compaction, stiffness, moisture, QC activities, and corrective actions (weekly report)	90% of the roller compaction measurements and average of LWD modulus measurements (based on 3 tests) must be at 90% of the target values established in the calibration strip.	Same during calibration and production compaction	
ISSMGE [Earthwork]	Roller chosen by experience	100 m by the width of the site	Homogenous, even surface. Track overlap ≤ 10% drum width.	Rolling pattern, sequence of compaction and measuring passes; amplitude, speed, dynamic measuring values, frequency, jump operation, and corresponding locations	Correlation coefficient ≥ 0.7. Minimum value ≥ 95% of Ev1, and mean should be ≥ 105% (or ≥ 100% during jump mode). Dynamic measuring values should be lower than the specified minimum for ≤ 10% of the track. Measured minimum should be ≥ 80% of the specified minimum. Standard deviation (of the mean) must be ≤ 20% in one pass.	Constant 2–6 km/h (± 0.2 km/h)	Constant (± 2 Hz)
Austria [Earthwork]	Vibrating roller compactors with rubber wheels and smooth drums suggested	100 m long by the width of the site	No inhomogeneities close to surface (materials or water content). Track overlap ≤ 10% drum width.	Compaction run plan, sequence of compaction and measurement runs, velocity, amplitude, frequency, speed, dynamic measuring values, jump operation, and corresponding locations	Correlation coefficient ≥ 0.7. Minimum value ≥ 95% of Ev1, and median should be ≥ 105% (or ≥ 100% during jump mode). Dynamic measuring values should be lower than the specified minimum for ≤ 10% of the track. Measured minimum should be ≥ 80% of the set minimum. Measured maximum in a run cannot exceed the set maximum (150% of the determined minimum).Standard deviation (of the median) must be ≤ 20% in one pass.	Constant 2–6 km/h (± 0.2 km/h)	Constant (± 2 Hz)
Research Society for Road and Traffic (Germany) [Earthwork]	Self-propelled rollers with rubber tire drive are preferred; towed vibratory rollers with towing vehicle are suitable.	Each calibration area must cover at least 3 partial fields ~20 m. long	Level and free of puddles. Similar soil type, water content, layer thickness, and bearing capacity of support layers. Track overlap ≤ 10% machine width.	Dynamic measuring value; frequency; speed; jump operation; amplitude; distance; time of measurement; roller type; soil type; water content; layer thickness; date, time, file name, or registration number; weather conditions; position of test tracks and rolling direction; absolute height or application position; local conditions and embankments in marginal areas; machine parameters; and perceived deviations	The correlation coefficient resulting from a regression analysis must be ≥ 0.7. Individual area units (the width of the roller drum) must have a dynamic measuring value within 10% of adjacent area to be suitable for calibration.	Constant	
Vägverket (Sweden) [Earthwork]	Vibratory or oscillating single-drum roller. Min. linear load 15–30 kN.	Thickness of largest layer 0.2–0.6 m.	Layer shall be homogenous and non-frozen. Protective layers < 0.5 m may be compacted with sub-base.	—	Bearing capacity or degree of compaction requirements may be met. Mean of compaction values for two inspection points ≥ 89% for sub-base under road base and for protective layers over 0.5 m thick; mean should be ≥ 90% for road bases. Required mean for two bearing capacity ratios varies depending on layer type.	Constant 2.5–4.0 km/h	—

Summary of existing roller-integrated compaction monitoring technology earthwork specifications (Continued)

Spec.	Equipment	Field Size	Location Specs	Documentation	Compaction Specs	Speed	Freq.
Iowa DOT (SP-090048) [HMA]	Self-Propelled vibratory dual drum break down HMA roller (Comply with Iowa DOT Article 2001-05 Standard Specifications). Provide a computer screen in the cab for viewing results.	—*	—*	Machine model, type, and serial/machine number; roller drum dimensions (width and diameter); roller and drum weights; file name; date stamp; time stamp; RTK based GPS measurements showing Northing, Easting, and Elevation; Roller travel direction; Roller speed; Vibration setting (i.e., on or off); Vibration amplitude; Vibration frequency; Surface temperature; Pass count; Compaction measurement value	IC data shall be collected and provided for a minimum 80% of the project surface and intermediate HMA quantity. QA for HMA is based on cores according to Section 2303 Iowa Standard Specifications.	Constant (min. of 10 impacts per linear foot and within ± 0.5 mph)	Constant (± 125 vpm)
Iowa DOT (SP-090057a) [HMA]	Self-Propelled vibratory dual drum break down HMA roller (Comply with Iowa DOT Article 2001-05 Standard Specifications). Provide a computer screen in the cab for viewing results.	—*	—*	Machine model, type, and serial/machine number; roller drum dimensions (width and diameter); roller and drum weights; file name; date stamp; time stamp; RTK based GPS measurements showing Northing, Easting, and Elevation; Roller travel direction; Roller speed; Vibration setting (i.e., on or off); Vibration amplitude; Vibration frequency; Pass count; Surface temperature.	IC data shall be collected and provided for a minimum 80% of the area of each HMA course. QA for HMA is based on cores according to Section 2303 Iowa Standard Specifications.	—	—
Iowa DOT (SP-090058) [HMA]	All compaction equipment must comply with Iowa DOT Article 2001-05 Standard Specifications. Provide a computer screen in the cab for viewing results on all equipment.	—*	—*	Machine model, type, and serial/machine number; roller drum dimensions (width and diameter); roller and drum weights; file name; date stamp; time stamp; RTK based GPS measurements showing Northing, Easting, and Elevation; Roller travel direction; Roller speed; Pass Count.	IC data shall be collected and provided for a minimum 80% of the project surface and intermediate HMA quantity. QA for HMA is based on cores according to Section 2303 Iowa Standard Specifications.	—	—
Iowa DOT (SP-090063) [Earthwork (only on materials with moisture control)]	Self-propelled padfoot roller weighing at least 10,800 kg.	Test strips to demonstrate the equipment meets the specs. 5 m wide x 75 m long compacted for 12 passes.	IC roller shall be used for measurement at vertical intervals of 0.6 m or less in proof areas. Surface shall be relatively smooth and uniform.	Machine model, type, and serial/machine number; roller drum dimensions (width and diameter); roller and drum weights; file name; date stamp; time stamp; RTK based GPS measurements showing Northing, Easting, and Elevation; Roller travel direction; Roller speed; Vibration setting, amplitude, and frequency (if vibration used); Surface temperature; Compaction measurement value	IC measurements in forward direction only on test strips and proof areas. IC data shall be collected and provided for a minimum 80% of the required proof areas. QA in proof areas is based on DS-09003 earthwork specification.	Constant on test strips and proof areas	

3. Guidelines for IC Developmental Specifications — David White and Pavana Vennapusa

The following are considered key attributes of IC specifications. Although current IC specifications (Table 1) have common language for many of these attributes, the largest dissimilarities exist with attribute 10 and are discussed further below.

1. Descriptions of the rollers and configurations,
2. Guidelines for roller operations (speed, vibration frequency, vibration amplitude, and track overlap),
3. Records to be reported (time of measurement, roller operations/mode, soil type, moisture content, layer thickness, etc.),
4. Repeatability and reproducibility measurements for IC measurement values (IC-MVs),
5. Ground conditions (smoothness, levelness, isolated soft/wet spots)
6. Calibration procedures for rollers and selection of calibration areas,
7. Simple linear regression analysis between IC-MVs and point measurements,
8. Number and location of quality control (QC) and quality assurance (QA) tests,
9. Operator training, and
10. Acceptance procedures/corrective actions based on achievement of minimum MV-TVs (MV target values) and associated variability.

Table 1. Summary comparison between current IC specifications

Specification	Target IC-MV	Acceptance Criteria	QA/QC Test Frequencies
ISSMGE (2005)	MV-TV = MV at 1.05% QA-TV from calibration (with r > 0.7 in linear regression between MVs and QA test measurements)	• Average MV ≥ MV-TV • If minimum MV ≥ MV at 0.95 x QA-TV, MV-COV shall be ≤ 20% • Minimum MV for a measuring pass shall not be ≤ MV at 0.95 x QA-TV for a maximum length of 10% of track length • Minimum MV for a measuring pass shall not be < 80% of 0.95 x QA-TV • Maximum MV ≤ 150% of MV at 0.95 QA-TV	— GUIDELINES FOR IC DEVELOPMENTAL SPECIFICATIONS
Mn/DOT (2007)	IC-TV = 90% of IC-MVs within 90%-130% of a trial MV-TV at point of no significant increase in compaction*	• MV for 90% of area within 90% to 130% of MV-TV • Localized areas IC < 80% of MV-TV reworked until MV ≥ 90% MV-TV	1 per 300 m for the entire width of embankment

*IC-TV is established using an iterative method by grouping the calibration MV data into distribution limits (i.e., >130%, 90%-130%, <80% of MV-TV) based on a trial MV-TV. If a significant portion of the grade is more than 20% in excess of the selected MV-TV, a new calibration strip may be needed.

IC Specification Options

Option 1: Roller based QC with pre-selected MV-TVs

For this specification option, an appropriate MV-TV is pre-selected based on documented case histories/literature, a database of information from local projects, laboratory tests, calibration tests on test beds of known engineering properties, mechanical apparatus simulating a range of soil conditions, and/or numerical modeling. The contractor uses the preselected MV-TV primarily for QC. QA is evaluated using a combination of IC-MVs and in situ QA point measurements. This option will become more beneficial as experience and data become available through implementation of IC on earthwork projects.

Option 2: IC-MV maps to target locations for QA point measurements

IC-MV geo-referenced maps are used in this specification option to identify "weak" areas to focus on QA point measurements. Proper QC measures (e.g., controlling moisture content, lift thickness, etc.) should be followed during compaction. The contractor should provide the IC-MV map to the field inspector for selection of QA test locations. Judgment is involved with selecting the number of tests and test locations. Acceptance is based on achievement of target QA point measurement values in roller identified "weak" areas. If in-situ test QA criteria are not met, additional compaction passes should be performed and/or QC operations should be adjusted (e.g. moisture, lift thickness, etc.) and retested for QA.

Option 3: MV-TVs from compaction curves to target locations for QA point measurements

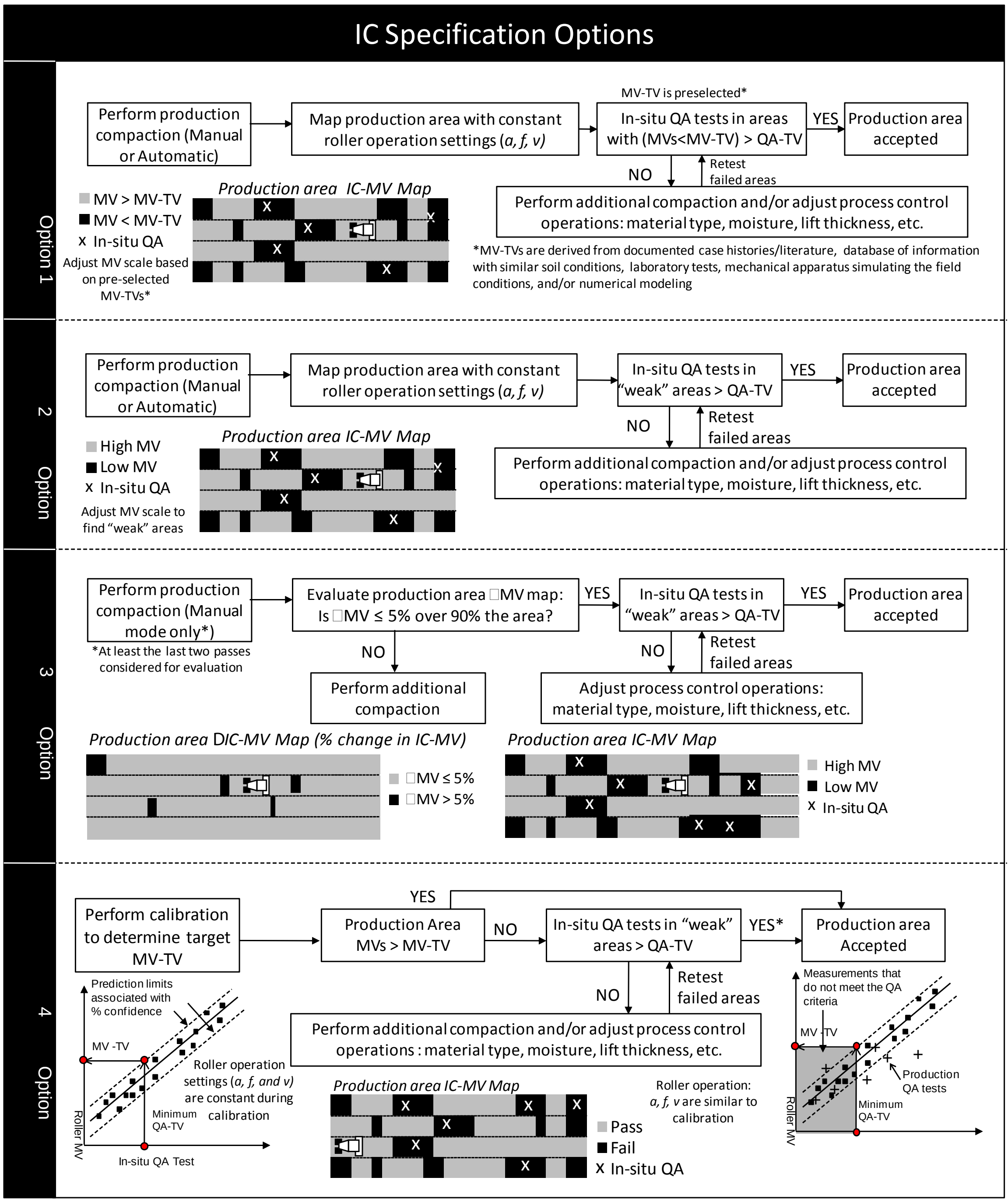
This specification option evaluates the change in IC-MVs with successive passes as an indicator of compaction quality. As the number of roller passes increases, the change in MV between passes normally decreases. A production area is monitored by evaluating the percent change in IC-MVs between successive passes. Once the percent change of ≤ 5% over 90% (these percentages can be adjusted based on judgment and field experience) of the production area between roller passes is achieved, the production area is considered fully compacted. This option is more effective for controlled field conditions with relatively uniform materials, moisture content, and lift thickness and serves as a QC process control for the roller operator. Judgment is involved with selecting the number of tests and test locations. Acceptance is similar to Option 1, in that QA testing is targeted in areas with relatively low IC-MVs.

Option 4: Calibration of IC-MVs to QA point measurements

This specification option requires calibration of IC-MVs to QA point measurements from a representative calibration test strip prior to performing production QA testing. The MV-TV is established from project QA criteria through regression analysis and applying prediction intervals. For modulus/strength measurements simple linear regression analysis is generally suitable, while for correlation to dry unit weight/relative compaction measurements, multiple regression analysis including moisture content as a variable may be needed. If underlying layer support conditions are heterogeneous, relationships are likely improved by performing multiple regression analysis with IC-MV or point measurement data from underlying layers. Acceptance of the production area is based on achievement of MV-TV at the selected prediction interval (80% is suggested) and achievement of target QA point measurement values in the areas with MVs < MV-TV.

Option 5: Performance based QA specification with incentive based payment

One of the shortcomings of the existing IC specifications might be that the acceptance criteria (specifically the target limits) are dependent on specific IC technology. This specification option, although requires a more rigorous statistical analysis framework, could provide a consistent means for specifying acceptance criteria. The acceptance criteria for this option are: (a) the overall level of critical soil engineering properties over an area achieve the MV-TV, and (b) the variability of critical soil engineering properties over an area is no more than some specified maximal amount (e.g., COV%). These acceptance criteria are established based on regression analysis from calibration, applying prediction intervals, accounting for the repeatability and reproducibility errors associated with IC-MVs and point measurements, and a selected probability or risk level in acceptance decisions. This approach could provide a link to performance-based specifications and a quantitative mechanism to define incentive-based payment.



4. Results of 2009 IC Workshop Breakout Sessions on IC Specifications

Intelligent Compaction Specifications

Goals

- Develop a specification that is not technology specific.
- Define what DOTs want to measure and format of the data.

Challenges

- Calibration of IC outputs to …?
- Data filtering for acceptance?
- Compatibility of different systems?
- Existing specifications are technology specific.
- Will never be able to keep up with a "technology spec"; need to shift the technology to the contractor.
- DOTs need to agree upon what end result properties they want to measure—"gold standard."
- Soils and asphalt will need separate specifications.
- IC use for QA requires FHWA verification.
- What is the IC tool for the state agency?

Key Attributes of IC Specifications

- Descriptions of the rollers and configurations, GPS (accuracy), other position technology?
- Guidelines for roller operations (speed, vibration frequency, vibration amplitude, and track overlap) (normalization).
- Records to be reported: time of measurement, roller operations/mode, soil type, moisture content, layer thickness, etc.; electronic output, portable, how often?, real-time viewing?, anti-data manipulation; format, # passes; roller operator ID.
- Repeatability and reproducibility measurements for IC measurement values (IC-MVs).
- Ground conditions (smoothness, levelness, isolated soft/wet spots/high GWT, variation of materials).
- Calibration procedures for rollers and selection of calibration areas (variable soils), (independent site/mechanical, see superpave).
- Simple linear regression analysis (statistical analysis, populations?) between IC-MVs and point measurements (moisture content, stiffness).
- Number and location of quality control (QC—what testing for w%, DD?) and quality assurance (QA—what testing/independent) tests.
- Operator training and certification.
- Basis of payment/incentives.

- Acceptance procedures/corrective actions based on achievement of minimum MV-TVs (MV target values) and associated variability. (When—construction traffic, etc.?) (QA—if contractor data used needs to be verified).

Key Discussion Points

- Stiffness may be a good alternative to traditional density measurements.
- IC for HMA—primarily a QC tool.
- Need guidance on linking values to location/depths in fill.
- Using IC data should lead to better quality.
- Traditional methods rely heavily on the experience of the inspector.
- Need certification/calibration of roller and operator.
- Moisture content is critical.
- What electronic output file will be required?
- When will acceptance occur, especially on bigger project.
- How to define acceptance so IC requirements are realistic.
- Pavement roughness/FWD test protocols.

Next Steps

- Education—identify benefits.
- Technology transfer involving manufacturers, contractors, and state DOTs.
- High-quality DVD.
- Develop stand-alone tools/software for field inspectors.
- Develop consensus approach for specification.

From the discussion, three main points can be summarized, as shown in Table 5.

Table 5. Summary of Specification Needs

Summary of Specification Needs

1. **Different IC technologies exist and are evolving, so specifications should be technology independent.**
2. **Protocols for reporting, transfer, and evaluation of electronic data need to be developed.**
3. **QA measurement may need to move away from traditional density to mechanistic-based (e.g., strength, stiffness).**

5. Summary of Current Specifications [Draft] — Pavana Vennapusa and David White

Summary of current state DOT specifications (Draft V[1])

Prepared by Pavana Vennapusa and David J. White

Earthworks Engineering Research Center, Iowa State University

Updated December 13, 2010

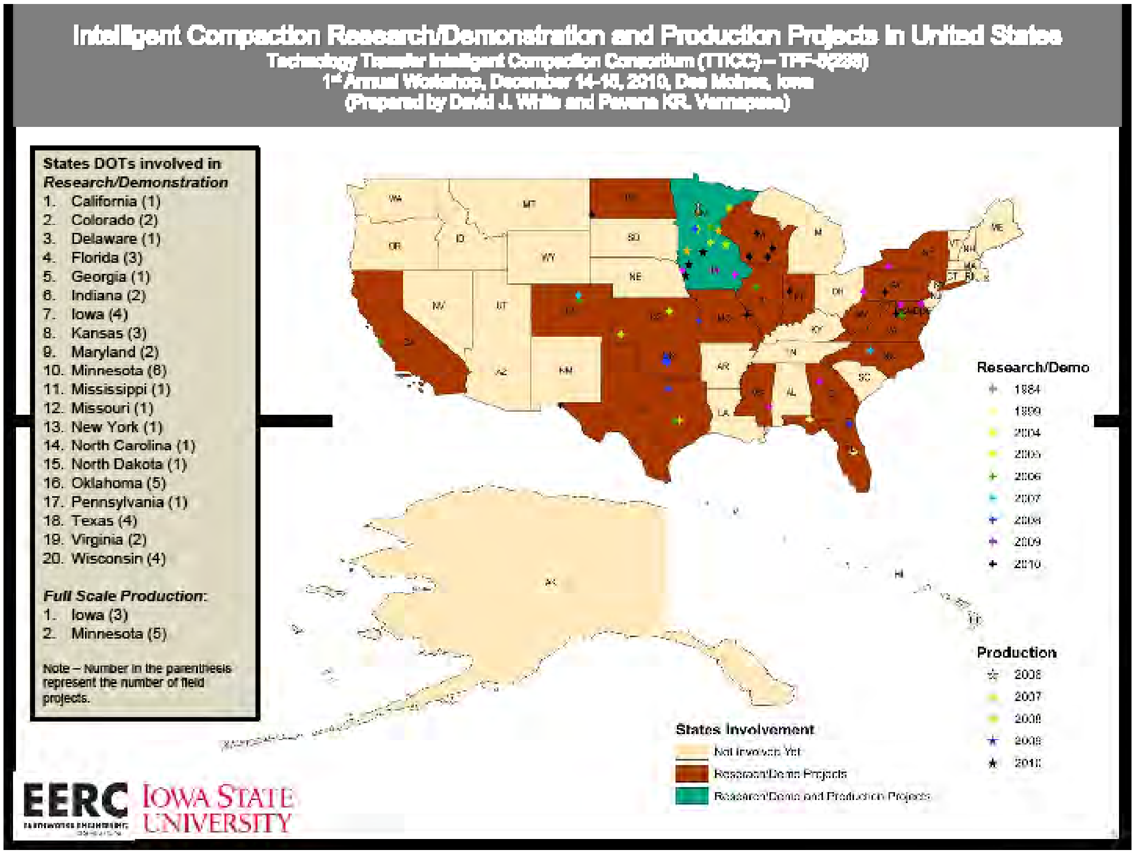
Summary of Current State DOT Specifications for Earthwork

State	Title	Key Attributes	Quality Control (Key items)	Quality Assurance	Testing Frequency
IA	Embankment (Section 2107)	• Materials • Equipment • Preparation of site • Depositing embankment material • Compaction • Rock fills • Granular blankets • Rebuilding embankments • Compaction trench bottom • Use of unsuitable soils • Embankments adjacent to existing structures • Method of measurement • Method of payment • Basis of payment	Lift thickness: 8 in (200 mm) loose except for rock fills/granular blankets. Type A/B Compaction: Moisture content should be suitable for satisfactory compaction. Compaction with moisture and density control: Moisture content should be within specified limits.	• *Using Type A Compaction*: One roller pass per inch depth of each lift. Compaction until roller is supported on its feet. • *Using Type B Compaction*: Specified number of disking and roller passes. One disking pass per 2 inches depth of each lift, and one roller pass per inch depth of each lift. Compaction until roller is supported on its feet. • *Using compaction with moisture and density control*: First layer compacted to a minimum of 90%, and succeeding layers to a minimum of 95% of standard Proctor density. Moisture content shall be within the specified limits. • *§Using compaction with moisture control*: Moisture condition material to within specified limits and compact using Type A compaction method.	?
MO	Embankment (Section 203)	• Classification of excavation • Borrow • Construction requirements • Compaction of embankment and treatment of cut areas with moisture and density control, without moisture/density control, and without specified compaction equipment • Method of measurement • Basis of payment	Lift thickness: 8 in (200 mm) loose in all areas except outside road way limits. 12 inches loose in areas outside roadway limits. Moisture should be within specified limits.	• *Construction with moisture and density control:* The embankment cut/fill areas that are 18 inches below the roadway fill level should be compacted to a minimum of 90% of standard Proctor density. All other areas require 95% of standard Proctor density. • *Construction without moisture/density control:* The embankment cut/fill areas that are 18 inches below the roadway fill level should be compacted to a minimum of 90% of standard Proctor density. All other areas require 95% of standard Proctor density.	?
	Aggregate Bases (Section 304)	• Material • Construction requirements • Quality control/quality assurance • Method of measurement • Basis of payment • Material inspection guidelines	Material should be placed/spread without segregation. Millings or recycled concrete shall be placed in maximum 4 in lifts and compacted using three passes using a 10 ton roller. Material should meet the density, thickness, gradation, deleterious, and plasticity index.	• Engineer to observe compaction operation to ensure the material forms a firm and stable base. • Measure and record the random thickness and template of the finished aggregate base. • Obtain material properties (density, gradation, presence of deleterious materials, PI) at specified frequency.	Density/moisture? Gradations – 1 per week and at least 1 per 16,000 tons PI – 1 per project with at least 1 per 80,000 tons
OH	Embankment (Items 203, 204)	• Material Definitions • Restrictions on the use of embankment materials • General • Embankment construction methods • Spreading and compacting • Compaction and moisture requirements • Earthwork construction tolerances • Method of measurement • Basis of payment	Lift thickness: 8 in (200 mm) loose Minimum compactive effort required (no. of roller passes and type of roller/weight, and moisture conditioning, depending on soil type and roller are specified. All materials except rock and shale must have moisture/density control.	• One-point Proctor method: If the maximum dry density is between 90 to 105 lb/ft³, then 102% relative compaction is required. If the maximum dry density is between 105 to 120 lb/ft³, then 100% relative compaction is required. If the maximum dry density is > than 120 lb/ft³, then 98% relative compaction is required. Aggregate correction is required for granular materials. • Test section method (applicable for granular soils with 25% or greater retained on ¾ in sieve): The material should be compacted to 98% of maximum density achieved from a minimum of 10 passes (or until density stops increasing) using a 10 ton smooth drum roller on the test section. • Proof rolling: Testing for stability and uniformity using a heavy pneumatic tire (90 to 150 psi) wheel roller with 25 to 50 tons (the tire pressure and load are adjusted based on soil type).	?

Summary of Current State DOT Specifications for Earthwork (Continued)

State	Material	Key Attributes	Quality Control (Key items)	Quality Assurance	Testing Frequency
OH	QC/QA for Embankment (Supp. Spec 879)	• Description • Contractor QC plan • QC plan acceptance • Acceptance of field inspection personnel • Notification of non-compliance • QA testing • Incentive pay adjustment • Basis of payment	Contractor to submit a QC plan at preconstruction conference which outlines personnel requirements, field test methods, test equipment, compaction equipment, and reporting structure.	• QA according to Items 203 and 204. • Incentive pay adjustment: Pay adjustments are assigned to the final quantities based on the total number of QA tests and the number of passing QA tests (PPAQT). Applicable Range of PPQAT / Pay Factor Formula (PFF): 90 to 100% : 1.00 + 0.04 [(PPQAT-90)/10.0] 70 to 90% : 1.00-0.04 [(90-PPQAT)/20.0] Below 70% : 0.96	?
	Unbound materials (Supp. Spec 1015)	• Definitions • Referenced standards • Apparatus • Forms • Procedure • Shale • Compaction acceptance • Number of tests	When vibration is used in test sections, adjust the vibration as necessary to prevent instability. Reduce moisture content if material becomes unstable.	• Size of test section to determine compaction target value: Embankment subgrade/base – 400 sq. yd. Trench backfill – 10 sq. yd., Granular backfill for MSE walls – 40 sq. yd. • Three different methods for constructing test sections based on soil type are discussed. • Rocks, hard shale, and open-graded granular – acceptance based on minimum roller passes (with or without compaction and moisture). • All other soils – acceptance based on compaction and moisture (with or without minimum roller passes and lift thickness).	One per lot with at least one per lift (typical lot size varies from 2000 to 3000 cu. yd. depending on material type).
UT	Embankment, borrow, backfill (Sect. 02056)	• Submittals • Acceptance • Material descriptions • Preparation • Embankment placement • Granular borrow and backfill placement • Embankment for bridge placement • limitations	Lift thickness: 12 in (300 mm) loose Do not place large rock within 1 ft of subgrade surface.	• Embankment, embankment for bridge, granular borrow, and subgrade placements: Soil classification (one per lot – source/soil type or every 20,000 cu. yds or 30,000 tons), Proctor (one per lot – source/soil type or every 20,000 cu. yds or 30,000 tons), and field density (one per sublot with 5000 sq. yds per lift, 15,000 sq. yds in cut sections) • Embankment for bridge: field density (six random locations per one foot lift) [96% of standard Proctor density for embankment] • Free draining granular backfill: Sieve analysis (one per 500 tons) • Backfill placements: Soil classification (one per lot – source/soil type or every 20,000 cu. yds or 30,000 tons), laboratory Proctor (one per lot – source/soil type or every 20,000 cu. yds or 30,000 tons), and field density (four random locations per 1000 sq. yd. or less lot) [96% of standard Proctor density]	
	Untreated base (Sect. 02721)	• Submittals • Acceptance • Material descriptions • Installation	Moisture condition material to ±2% of modified Proctor optimum during placement. Thickness of each lift should not exceed 6 inches.	• Under pavements - Meet gradation limits and applicable tolerances. One sample from each sublot. Meet minimum density with average of 97% and no test less than 94% of Proctor maximum density.	
WI	Subgrade	• Description • Materials (QC plan, personnel, laboratory, equipment) • QC documentation • Contractor testing (field density/moisture, one-point Proctor, testing frequency, compaction zones, control limits) • Department testing (verification/independent assurance testing) • Dispute resolution • Acceptance • Payment	• Lower control limit for density measurements in the upper zone is a min. of 95% of standard Proctor density for the 4-point running average and 92% for any individual test. For lower zone the minimum limit is 93% for the 4-point running average and 90% for any individual test. • The upper and lower control limit for the moisture content are 65% and 105% of the standard Proctor optimum moisture content for the 4-point running average. No control limit for soils with 5% or less passing the No. 200 sieve. • Subgrade Embankment: Field density and moisture – one per 3,000 cu. yds. One-point Proctor – one per 9,000 cu. yds. • Subgrade Cut : Field density and moisture – one per cut area or one per 2,000 linear feet per roadway • Subgrade Embankment in culvert pipe trenches: Field density and moisture – one per trench. If larger pipes (>40 in dia.) 2 per trench on different lifts. One-point Proctor – one per 3,000 yd^3. • Structure and granular backfill at bridge abutments: Field density and moisture - 2 per abutment on different lifts. One-point Proctor – one per 3,000 cu. yds.			
VA		•			
CA		•			
MS		•			
KY		•			
GA		•			
PA		•			

6. IC Projects Map — David White and Pavana Vennapusa



Questions/Comments and Responses

The following is a log of the questions/comments from the participants and responses from the presenters during the Day 1 workshop presentation sessions.

GA DOT Question: Is there any software tool already developed within GIS to record/store data? Can industry (like Trimble) help write such software?

Response: Minnesota DOT sponsored a research project on this topic. There are still issues on wireless data transfer, data filtering, and presentation (points to lines/polygons in GIS).

WI DOT Comment: WI wants to move away from density testing. Currently working on a research project looking at other non-nuclear and stiffness based testing methods.

GA DOT Comment: GA looked at demonstrations on non-destructive testing. Mostly it was research and no movement was seen to implement the devices yet.

Univ. of KY Question: It appears that all roller manufacturers have their own measurement system. Can this standardized?

Response: It is definitely advantageous to standardize the output format, but the measurement values. It's probably more helpful to focus on correlations with a "gold" standard measurement that everyone is comfortable with.

GA DOT Question: Using strength based measurements such as CBR value has been a concern in GA due to its variability and poses a concern using it as a QA measurement.

Response: Density is much less variable compared to modulus and strength based measurements.

WI DOT Comment: It is important to find a way to link the IC measurements to the traditional measurements. This will help advance implementation.

Univ. of KY Comment: KY did a permeability measurement specification on asphalt with % limits of target value and applied pay factors in the specification based on those limits.

Univ. of KY Comment: It may not be easy to use pay factors for earthwork like in case of asphalt. We will have to fix problems during construction and it does not help paying less in the end for quality.

OH DOT Comment: Density is less variable compared to other measurements with less "noise". It appears that there is a lot of "noise" in the IC data and it would be tough to pick a value as it is so variable.

Response: IC data shows good repeatability. There are variability in the data, which is mostly because of the variations in the soil stiffness and not because of "noise" in the data. Statistically, soil stiffness has much higher coefficient of variation than density.

VA DOT Comment: How do we handle moisture content with stiffness testing. Dry side of optimum results in very high stiffness, where moisture is clearly a problem. How do we address that issue?

Response: We cannot exclude moisture content as part of QC/QA, and should be independently measured.

GA and WI DOT Comment: As moisture for soil, temperature is the number one issue with asphalt. We need advancements in moisture and temperature measurements to make advancements and save costs.

WI DOT Comment: There has been demonstrated evidence with benefits on Automated Machine Guidance (AMG), and therefore there has been good move toward implementation. Its important we do the same with IC technology to get contractor's buy-in. Does DOT have to provide incentives?

Group discussion/comments:

- On big projects, contractor can save a lot of money by cutting down costs on QC. Should not cut down on number of QA.
- DOT still has to do all QA.
- Currently, MO and IA DOTs check 1 in every 10 contractor's QC test, but do all QA tests. KY does only QA and no QC. IC can be very beneficial for states that do not do QC at all.
- Testing a location based on GPS co-ordinates can be an issue. It incurs cost on DOT to provide all inspectors with GPS. Currently, some DOTs are not setup for that. Should contractor provide the equipment?
- IA DOT bough GPS equipment for all district offices and most of them are utilizing the equipment on field projects.
- How do we address soil variability if the IC measurements are sensitive to changes in soil type? How can we make sure operator pays attention to soil type changes?
- We need data management, archival, and analysis guidelines in the specification.

Breakout Sessions

On day one, two separate two hour long breakout sessions were conducted by separating the workshop participants into two groups. Each group had a facilitator. Brief agenda used to facilitate discussion in the breakout sessions is provided below.

- Review the road map with the 12 research, implementation, and educational topic areas identified in the 2010 IC webinar workshop report3. The participants were asked to provide comments regarding topics that should be removed, revised, or added.
- Develop an updated road map by ranking the topic areas using participant voting. Each participant was allowed 5 votes and could apply the votes to any of the topic areas.
- Discuss and debate the top 3 topic areas resulted from the voting.
- Identify action plans, leadership roles, and potential funding needed to move forward on the top 3 topic areas.
- Discuss future workshop meetings, its format, and about who to participate.
- Results from each breakout session are provided below. The outcomes were presented on day 2 by each session leader and facilitator.

Breakout Session #1

Facilitator: Pavana Vennapusa (EERC, Iowa State Univ.)

Participants: Peter Narsavage (Ohio DOT), Melissa Serio (Iowa DOT), Edward Hoppe (Virginia DOT), Jeff Schmidt (Iowa DOT), William Stone (Missouri DOT), Mark Dunn (Iowa DOT), Ian Rish (Georgia DOT), Jonathan Fisher (Univ. of Kentucky).

Prioritized Ranking of 2010 IC Workshop Road Map Topic Areas (# in parenthesis represent the number of votes)

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

Suggestions/Additions/Discussion on Top 3 Topic Areas

(1)Intelligent Compaction and In-Situ Correlations

- Need to define "gold" standard measurement.
- Correlation studies with traditional density measurements are important to conduct.
- Need correlations with PQI for HMA.
- Need more correlations with FWD.
- Future studies with correlations on WMA.
- Future work on Roller Compacted Concrete?
- Need understanding on which QC device produces better correlations (depending on soil type).

(2)Intelligent Compaction Specifications and Guidance

- It's a good start with using IC for QC only. There might be issues with using IC for QA.
- Start with pilot projects with recording only pass count/elevation information to gain experience – for e.g., as being done in Iowa.
- Need to develop a technology independent "umbrella" specification to be able to use different QC devices and IC technologies.
- Need to address "Equipment Specifications" for IC equipment.
- Need to address training/education aspects within the specifications.

(3)Standardization of Roller Outputs and Format Files

- Develop a database schema for data archival purposes.

Action Items

- Develop IC/tech briefs with information on different QC devices and correlations.
- Prepare a summary table with QC device applicability linked to soil type based on existing information.
- Conduct field demonstration projects. KY is interested in doing asphalt demonstration projects and GA is interested in doing soil/base demonstration projects.
- Work with interested contractors in the state to get their buy-in and implement on IC a pilot project [OH and MO].
- Conduct a survey among different states to learn from their experiences [need to contact the right persons in each DOT].
- European experience? (May want to contact TRL in UK, LCPC in France, BAST in Germany).
- Need more FHWA involvement.

Discussion on Future Meetings

- Need industry (manufacturer) presentations for at least half-day on day 1. This will give DOTs a better chance to interact with industry personnel to know about the status of the availability of the equipment and also know more about the technology.

Breakout Session #2

Facilitator: Heath Gieselman (EERC, Iowa State Univ.)

Participants: Stephen Megivern (Iowa DOT), Sandra Larson (Iowa DOT), James Lee (California DOT), Alfred Casteel (Georgia DOT), Brent Gaschler (Utah DOT), Barry Paye (Wisconsin DOT), David White (EERC, Iowa State Univ.), Kean Ashurst (Univ. of Kentucky).

Prioritized Ranking of 2010 IC Workshop Road Map Topic Areas (# in parenthesis represent the number of votes)

1. IC Compaction and In situ Correlations (8)
2. IC Specifications Guidance (7)
3. Data Management and analysis (6)
4. Project Scale Demonstrations and Case Histories (4)
5. Education/Certifications Programs (4)
6. IC Compaction Research Database (3)
7. Understanding Impact of Non-Uniformity on Performance (3)
8. In Situ Testing Advancements and New Mechanistic Based QC/QA (2)
9. Understanding Roller Measurement Influence Depth (1)
10. IC Technology Advancements and Innovations (1)
11. Sustainability (1) *new topic
12. Standardization of Roller Outputs and Format Files (0)
13. Standardization of Roller Sensor Calibration Protocols (0)

Action Items

- Compile a database to evaluate correlations of in situ measurements to IC measurement values. Evaluate in situ measuring tools.
- Use output from #1 to develop technology independent guide/common/sample specification. Invite FHWA, industry, manufacturers, contractors, and state agencies to review.
- Develop tech brief that explains methods/strategies of data analysis. Develop data analysis software by involving computer programmers.
- Conduct open house and demo projects. Find suitable locations.
- Work toward development of NHI course and certification for operators, inspectors and engineers.

Discussion on Future Meetings

- Meeting at a field demonstration project?

Future Meetings, Research, and Technology Transfer Strategies – Discussion

The following were excerpts from the discussion following the breakout session reports on future meetings, research, and technology transfer strategies:

- TTICC group needs to keep the industry informed about the outcomes.
- Green Roads initiative – This might be a possible action item to consider and include a presentation for the next meeting to see how it fits with IC.
- There is need for a presentation at the next meeting on the state-of-the-art and –practice on real-time moisture (for soil) and temperature (for asphalt) measurements.
- There is need for a presentation at the next meeting on technologies that can precisely measure layer thickness especially for HMA.
- Future research and funding opportunities:
    - Conduct accelerated testing on controlled test sections with uniform and non-uniform conditions.
    - Florida, California, and Illinois have accelerated testing facilities.
    - FHWA Turner Fair Banks in Virginia, MnRoad in Minnesota, Auburn, Nevada, and Mississippi have test tracks that could also be utilized.
- Publish and distribute TTICC newsletter every 6 months by research bureau directors of the participating states to their peers in other states on progress/update to inform other states and encourage their partnership.
- Index the TTICC website on Google to show up on the first search page for intelligent compaction.
- TTICC future meetings
    - Telephone meetings once every 6 months (for overview and status update).
    - Face-to-face meetings once every year.
    - Next meeting – PA, CA, or GA?
- State DOT targets on implementation and specifications
    - Iowa DOT to conduct one demonstration/pilot project next year
    - Kentucky DOT is interested in conducting a demonstration project next year
    - Georgia DOT is interested in conducting a demonstration project for soils
    - Ohio DOT is interested in conducting a demonstration project – how can this work be coordinated through TTICC?
- Mark Dunn (Iowa DOT) – If any state DOT want to host a demonstration project as part of TTICC, they can add extra $ amount to cover for field testing and equipment

deployment costs for the EERC research group.

- Several state DOTs requested for an overview presentation emphasizing on the following aspects for executive level personnel in their DOT:
  - Why important?
  - What are the benefits for the Contractor?
  - What are the benefits for the DOT?
  - Basics of the technology.
  - Video showing how it works.
  - Overview of workshop activities and outcomes.
  - Historical information on what exists, where we are, where we need to be?
  - Timeline for implementation.
  - TRB outreach
  - Need to get a paper submitted every year co-authored by at least one in the group/participating states.
  - Need to show TTICC representation at the Earthworks Committee and Instrumentation Committee (some of the group members are attending these committee meetings at the TRB 2011 meeting)
- Lisa Rold (FHWA) – FHWA is currently evaluating few "Green" technologies as part of the Every Day Counts (EDC) initiative. IC is not currently included in the list of the technologies. Lisa to write a White Paper on how these different technologies benefit implementation in Iowa and would like to include IC as a potential technology. Would like to use the outcomes of this report on milestones and action plans identified, along with a potential list or number of demonstration/pilot projects that every state would like to conduct.
- Ian Rish (Georgia DOT) - Georgia is interested in inviting the EERC team and the Mobile Lab to do an open-house or demonstration at the Southeast Geotechnical Engineering Conference.
- David White (EERC) – It is important to note that a detailed experimental plan with proper and adequate testing is needed for a successful demonstration project.

Group Exercise to Identify Implementation Strategies

Following the discussion on future meetings, research, and technology transfer strategies, the participants were asked to break up into two groups for a group exercise to identify implementation strategies. The groups were charged with looking five years into the future and brainstorming reasons why implementation of IC was successful in their state – in DOT, contractor, and industry manufacturer's perspective. The questions posed to each group and the outcomes of their discussion are provided separately for each group below. Each group designated a leader to present the results to the rest of the team after a 10 to 20-minute brainstorming session for each question.

Question 1: *What specifically did you do to implement intelligent compaction technologies in your state?*

Group#1 Responses

- Conducted field demonstrations in the TTICC pooled fund states.
- Developed data analysis software and built a sound database with good, accurate, and reliable field data.
- Developed universal/general specifications to accommodate using different IC technologies.
- Developed data analysis software for quick decision making in field (go or no-go)
- Identified "gold" standard QA/QC measurement.
- Conducted annual workshops at TRB.
- Developed a certification program.
- Conducted pilot projects using IC technology.
- Produced white papers and synthesis reports using existing field case history information, demonstrating value in using IC.
- Industry is meeting the market demands with enough available rollers.

Group#2 Responses

- Developed pilot specifications and obtained funding for demonstration projects.
- Studied influence of moisture content and asphalt temperature on IC measurements, and linked stiffness to air voids on asphalt materials.
- Identified additional research needs.
- Developed and maintained a research database.
- About 30 states have conducted demonstration projects through FHWA initiatives.
- Developed simple data analysis software that displays "go or no-go" type results for field inspectors.

- Demonstrated construction efficiency (reduction in time) using IC through field demonstration projects.

Question 2: *What are the top 2 accomplishments in your state and what specific actions did you take to achieve those. Was the contractor on-board with your recommendations?*

Group#1

1.Conducted demonstration projects:

- Involved state DOT personnel in design, research, management, and construction divisions during all stages to get their support and buy-in to conduct these projects.

2.Developed specifications to conduct pilot projects:

- Used existing specifications to and drafted our own specifications to fit our local needs.

Group#2

1. Developed data analysis software:

- Built a sound database with data representative of cases and conditions nationwide.
- Developed mathematical models that are statistically valid and show good repeatability.
- Used the database to develop software to conduct the analysis required (software may be technology or company specific unless a unified IC technology comes forward).

2. Developed funding for technology advancement:

- Developed case history reports showing analysis of data from specific projects, and demonstrated lessons learned from each project and the benefits of the technology.
- Determined the next steps to be taken based on lessons learned from each project.
- The case histories were used by the states to develop funding channels to pilot projects in the state.

Question 3: *Think about the products you generated in a Contractors' perspective. As a contractor, what specific DOT action items or products were useful for you to be onboard with their recommendations?*

Group#1

- Well demonstrated benefits through field studies such as reduction in construction time and fuel costs, increase in productivity, and documentation of field operations.
- IC's potential in identifying problematic areas faster and bringing to DOT inspectors' attention to get direction on how to fix the problems.
- Using IC helped in developing a positive image on the company with forward thinking and concern for environment.

Group#2

- DOT's invitation to attend workshops and meetings and involving us in the specification development phase was helpful.
- Proved that it was more economical to the contractor with less full costs, more productivity by optimizing compaction process.

- Proved that the technology results in more consistent or uniform product and the contractors get incentives ($).
- Proved that the technology helps in identifying areas where additional compaction effort is not required and problematic areas that need additional compaction or other remedies to fix the problem.

Question 4: *Think about the products you generated in a Manufacturer's perspective. As a Manufacturer, what specific DOT action items or products were useful for you to be onboard with their recommendations?*

Group#1

- DOT helped us focus on product development by providing us with data and output requirements in the specifications.
- DOT's invitation for our input in specification development process.

Group#2

- DOT's Invitation to workshops and committee meetings. It served as a good forum to sell the technology and develop contacts, learn more about demonstration projects, and the agency needs.
- DOT's invitation for our input in specification development process.

The following two questions were posed to the whole group:

Question 5: *How many of the 13 research/implementation/educational topic areas would you like to accomplish in the next five years?*

- At least the top 2 or 3 topic areas. If these are completely addressed, the other topic areas will automatically get affected.
- 100% on top 2 or 3 topic areas. At least 50% on the rest of the areas.

Question 6: *What are the limiting factors that are causing delay in accomplishing all 13 topic areas?*

- Funding.
- Knowledge gap – DOT engineers not up to speed on the technology.
- Limited project opportunities to implement on pilot projects – lot of other technologies to implement on pilot projects and contractors do not encourage trying more than one technology demonstration on a pilot project.
- Logistics.
- Need for management/executive level champions.
- Equipment availability from industry.

IC Implementation Road Map

The IC Road Map, developed during the 2008 IC workshop meeting1 and updated at the 2009 and 2010 meetings[2,3], was evaluated again this year in the breakout sessions by separating the participants into two groups as described above. The prioritized list of IC technology research/implementation needs, by combining the results obtained from the two workshop sessions, is presented in Table 1. One new element was added to the list, and descriptions of the existing road map elements were modified (see Table 2) based on participants' feedback. Similar to the previous workshop outcomes, the top two needs remain (1) developing and providing evidence of correlations between IC/CCC measurements and in situ test measurements and (2) developing IC/CCC specifications/guidance.

Table 1. Prioritized IC technology research/implementation needs – 2010 TTICC workshop

Prioritized IC/CCC Technology Research/Implementation Needs

1. **Intelligent Compaction and In situ Correlations (24*)**
2. **Intelligent Compaction Specifications/Guidance (19*)**
3. **Data Management and analysis (8*)**
4. **Project Scale Demonstrations and Case Histories (7*)**
5. **Education/Certifications Programs (4*)**
6. **Understanding Impact of Non-Uniformity on Performance (4*)**
7. **Standardization of Roller Outputs and Format Files (4*)**
8. **IC Compaction Research Database (3*)**
9. **In Situ Testing Advancements and New Mechanistic Based QC/QA (2*)**
10. **Understanding Roller Measurement Influence Depth (1*)**
11. **IC Technology Advancements and Innovations (1*)**
12. **Sustainability** (1*)**
13. **Standardization of Roller Sensor Calibration Protocols (0*)**

*total votes are provided in parenthesis
**newly added roadmap element

Table 2. Revised IC road map research, implementation, and educational elements – 2010 TTICC workshop

IC Road Map Research, Implementation, and Educational Elements

1. Intelligent Compaction and In Situ Correlations [1*]. 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, 5, 6, 7, and 9. There is need to define "gold" standard QC/QA in-situ test measurement for correlations depending on the material type (i.e., soils, base, or asphalt).
2. 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.
3. Data Management and Analysis [7*]. 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 1, 2, 4, 5, 6, 8, and 10.
4. Project Scale Demonstration and Case Histories [5*]. 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 2, 5, and 6.
5. Education Program/Certification Programs [10*]. 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 than 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.
6. 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 1, 2, 4, 5, and 9.

7. **Understanding Impact of Non-Uniformity of 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 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 2, 3, and 5.**
8. **In Situ Testing Advancements and New Mechanistic Based QC/QA [3*]. 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.**
9. **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.**
10. **Intelligent Compaction Technology Advancements and Innovations [4*]. 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. **Sustainability**. 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.**
12. **Standardization of Roller Outputs and Format Files [8*]. This research element involves developing a standardized format for roller output and format files. This element crosscuts specification development (element 2).**
13. **Standardization of Roller Sensor Calibration Protocols [12*]. 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.**

* March 2010 webinar workshop ranking, **newly added roadmap element.

Key Outcomes and Proposed Action Items

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

1. Served as a forum for exchanging technical information and provided opportunities for future collaborations.
2. Updated and prioritized the IC/CCC technology research and implementation needs road map.
3. Developed list of key products that needs to be developed as part of the TTICC project.
4. Identified action items to advance IC/CCC technologies implementation into earthwork and asphalt construction practice.
5. Developed plans for future TTICC meetings and workshops, to further technology exchange activities and explore opportunities for implementation, education/training programs, and technological advancements.

Table 3 presents a list of products/items to be developed as part of the TTICC study. Table 4 identifies an action plan for the TTICC team for advancing IC/CCC technologies into earthworks and HMA practice based on the information derived from the workshop breakout sessions and discussions.

Table 3. List of products/items to be developed for the TTICC project

List of Products/Items to be developed for TTICC project
• Develop at least 20 IC briefs based on existing field demonstration projects/research reports in the US. Develop one IC brief a month.
• Update EERC's TTICC website regularly and include all IC briefs with videos, and updated information related to TTICC project activities and workshop findings.
• Develop a Technology Overview Presentation for executive level officials in DOT.
• Explore funding opportunities for writing synthesis documents explaining IC technologies, QC/QA correlations, etc.

Table 4. Action plan for advancing IC technologies into earthwork and HMA practices

Action Plan for Advancing IC/CCC Technologies into Earthwork and HMA

- **Develop case study information on different QC devices/correlations/ methods and strategies of data analysis.**
- **Compile a data base to evaluate correlations of in situ measurements to IC measurement values and evaluate in situ measurement tools.**
- **Develop Technology Independent Guide Specifications (FHWA/industry/ manufacturer/ contractors/stage agencies review)**
- **Develop data analysis software by involving computer programmers.**
- **Conduct demonstration projects and open houses. Work with interested contractors in the state to get their buy-in and implement IC on pilot projects.**
- **Conduct a survey among different states in the US and European countries to learn from their experiences.**
- **Work toward development of NHI course and certification for operators, inspectors and engineers.**
- **Submit problem statements to TRB/NCHRP to create funding opportunities.**

Appendices

Appendix A: Workshop Webinar Agenda

Technology Transfer for Intelligent Compaction Consortium (TTICC)
Des Moines, Iowa
December 14 –15, 2010

DAY 1

7:15	Breakfast (included)
8:00	Welcome – Sandra Larson, P.E. Iowa DOT Participant introductions (including technical focus/job responsibilities)
8:15	TTICC Goals, Objectives, Schedule – Mark Dunn, P.E. Iowa DOT
8:30	Review past IC Workshops/Road Map – David J. White, Ph.D., ISU
9:00	State DOT briefings on interests for IC implementation
10:00	Break
10:15	Overview of synthesis of traditional State specifications and QC/QA – Pavana Vennapusa, Ph.D., ISU
11:00	Overview of synthesis of IC specifications – Heath Gieselman, M.S., ISU
11:45	Lunch
1:00	Current happenings in IC/Recent Demo Projects/SHRP "Compaction Roadeo" – David White
2:00	Technology Transfer Products/Case History Template/Examples/Website/Wiki – David White
2:30	IC Road Map-DRAFT – David White
2:45	Break
3:00	Breakout session #1 (subgroups – research needs, implementation challenges) – Facilitators – Heath Gieselman/Pavana Vennapusa
3:45	Breakout session #2 (subgroups – research needs, implementation challenges) Facilitators – Pavana Vennapusa/Heath Gieselman
4:30	Wrap-up Dinner (included) - TBD

DAY 2

7:15	Breakfast (included)
8:00	Plan for morning session – Melissa Serio, Iowa DOT
8:05	Reports from breakout sessions – State DOT session leaders
9:00	Other states involvement/industry/academia in TTICC Future meetings plans – Mark Dunn
9:20	TRB outreach – Pavana Vennapusa
9:30	QC/QA devices impact on IC implementation – Heath Gieselman
10:00	Break
10:15	Group exercise to define success! – David White
11:15	Wrap-up and adjourn – Mark Dunn

Appendix B: Workshop Attendees

Scott Andrus
State Materials Engineer
VDOT Materials
4501 South 2700 West - MTF
Salt Lake City, UT 84114
801-965-4859
scottandrus@utah.gov

Kean Ashurst
Research Engineer
Univ Transportation Center
176 Raymond Bldg
Lexington, KY 40506
859-257-7319
kashurst@engr.uky.edu

Alaa Azab
mazab@state.pa.us

Bonnie Fields
bfields@state.pa.us

Jamie Bewley
jamie.bewley@ky.gov

Alfred Casteel
Testing Mgmt Branch Supervisor
Material and Research
715 Kennedy Dr
Forest Park, GA30297
404-694-6657
acasteel@dot.ga.gov

Haniel Chung
916-657-4064
haniel.chung@dot.ca.gov

Mark Dunn
Operations Research Engr
Research & Technology
800 Lincoln Way
Ames, IA 50010
515-239-1447
mark.dunn@dot.iowa.go

Jonathan Fisher
Research Engineer
Univ Transportation Center
176 Raymond Bldg
Lexington, KY 40506
859-257-7317
jsfisher@engr.uky.edu

Mike Fritz
mike.fritz@modot.mo.gov

Brent Gaschler
Technology & Support Engr
VDOT Materials
4501 South 2700 West - MTF
Salt Lake City, UT 84114
801-965-3816
bgaschler@utah.gov

Georgene Geary
State Materials Res Engr
15 Kennedy Dr
Forest Park, GA30297
404-608-4712
ggeary@dot.ga.gov

Heath Gieselman
Researcher
Earthworks Engineering Research Center
2711 S. Loop Dr, Suite 4700
Ames, IA 50010
515-294-7720
giese@iastate.edu

Edward Hoppe
Research Scientist
VDOT
530 Edgemont Rd
Charlottesville, VA 22903
434-293-1960
edward.hoppe@vdot.virginia.gov

Sandra Larson
Director, Research Bureau
Research & Technology
800 Lincoln Way
Ames, IA 50010
515-239-1205
sandra.larson@dot.iowa.gov

James Lee
PMS Engineer
Pavement Program
2789 Gateway Oaks Dr
Sacramento, CA 95833
916-274-6095
james_n_lee@dot.ca.gov

Jeremiah Littleton
jeremiah.littleton@ky.gov

Jill Martindale
jill.martindale@dot.state.oh.us

Stephen Megivern
Soils Design Section
800 Lincoln Way
Ames, IA 50010
515-239-1936
stephen.megivern@dot.iowa.gov

Peter Narsavage
State Const Geotech Engr
Office of Construction Admin
1980 W Broad St
Columbus, OH 43223
614-644-6638
peter.narsavage@dot.state.oh.us

Barry Paye
Pavement Warranty and Research Engr
Bureau of Technical Services
3502 Kinsman Blvd
Madison, WI 53704
608-246-3855
barry.paye@dot.wi.gov

Sharon Prochnow
Program Coordinator
Earthworks Engineering Research Center
2711 S. Loop Dr, Suite 4700
Ames, IA 50010
515-294-3781
prochnow@iastate.edu

Ian Rish
Geotechnical Engr
15 Kennedy Dr
Forest Park, GA 30297
404-608-4726
irish@dot.ga.gov

Brad Rister
Univ Transportation Center
brister@engr.uky.edu

Judith Ryan
Materials Management
Bureau of Technical Services
3502 Kinsman Blvd
Madison, WI 53704
608-246-5456
judith.ryan@dot.wi.gov

Jeffrey Schmitt
HMA Field Engineer
Office of Construction
800 Lincoln Way
Ames, IA 50010
515-239-1013
jeffrey.schmitt@dot.iowa.gov

Melissa Serio
Earthworks Field Engr
Office of Construction
800 Lincoln Way
Ames, IA 50010
515-239-1280
melissa.serio@dot.iowa.gov

William Stone
573-526-4328
william.stone@modot.mo.gov

Peter Vacura
HMA Office Chief
Pavement Program
2789 Gateway Oaks Dr
Sacramento, CA 95833
916-274-6194
peter.vacura@dot.ca.gov

Pavana Vennapusa
Research Faculty
Earthworks Engineering Research Center
2711 S. Loop Dr, Suite 4700
Ames, IA 50010
515-294-2395
pavanv@iastate.edu

James C. Watkins
State Research Engineer
PO Box 1850
Jackson, MS 39215
601-359-7650
jwatkins@mdot.state.ms.us

David White
EERC Director
Earthworks Engineering Research Center
2711 S. Loop Dr, Suite 4700
Ames, IA 50010
515-294-1463
djwhite@iastate.edu

Appendix C: Iowa DOT Special Provisions for Intelligent Compaction — HMA [SP-090048]

SP-090048
(New)

Iowa Department of Transportation

SPECIAL PROVISIONS
FOR
INTELLIGENT COMPACTION-HMA

Harrison County
NHSN-030-1(127)--2R-43

Effective Date
January 20, 2010

THE STANDARD SPECIFICATIONS, SERIES 2009, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

In addition to the requirements of Section 2303 of the Standard Specifications, the following shall apply:

090048.01 Description
This specification describes the Contractor's responsibilities for furnishing Intelligent Compaction (IC) equipped rollers, data acquisition, training, roller verification/repeatability testing, and transmitting data to the Engineer. IC for HMA is defined as the gathering of data from self-propelled vibratory roller systems involved with the measurement and recording of roller position, date/time, speed, vibration frequency, vibration amplitude, surface temperature, pass count, travel direction, and a compaction measurement value (MV). Real Time Kinematic (RTK) based Global Positions System (GPS) with base station corrections shall be used for determining the position of the roller. Results from the IC shall be displayed to the roller operator on a color coded computer screen in real-time during roller operations and the data saved for transfer and viewing by the Engineer.

Quality acceptance for IC-HMA will be based on cores according to Section 2303 of the Standard Specifications. The IC results will be used as a guide to supplement core sampling for research purposes. Secure a maximum of three additional cores per lot collected concurrently with acceptance cores based on viewing roller pass coverage, surface temperature during compaction operations, and IC compaction MVs. The Engineer will determine the location for the additional cores.

Submit to the Engineer an IC Work Plan at least two weeks prior to the Preconstruction Conference. Describe in the work plan the following:

- Compaction equipment to be used including:
  - Vendor
  - Roller model,
  - Roller dimensions and weights,
  - Description of IC measurement system,

- GPS capabilities,
- Documentation system,
- Temperature measurement system, and
- Software.

- Roller data collection methods including sampling rates and intervals and data file types.
- Transfer of data to the Engineer including method, timing, and personnel responsible. Data transfer shall occur at minimum once per day or as directed by the Engineer.
- Training plan and schedule for roller operators, Engineer's personnel, and Iowa State University's research personnel; including both classroom and field training.
- Communication protocol for informing the Iowa State University research team point of contact concerning construction progress and schedule to facilitate research field testing and data collection.

090048.02 Equipment and Materials

A. Rollers
Comply with Article 2001.05 of the Standard Specifications for self-propelled vibratory rollers. Article 2001.05 applies to all rollers used in the breakdown position. Breakdown roller is defined as the roller(s) making the initial contact with the HMA.

Ensure that IC equipment can measure roller position, date/time, speed, vibration frequency, vibration amplitude, surface temperature, pass count, travel direction, and a compaction measurement value (MV). Provide a computer screen in the roller cab for viewing measured results. Ensure that results are stored for transfer to the Engineer for viewing on a laptop computer. Provide the Engineer and Iowa State University each with a copy of the IC roller vendor software for viewing results. Ensure that results are displayed as color coded spatial maps based on GPS coordinates.

B. Data Collection, Export, and Onboard Display
Provide and export the following data in a comma, colon, or space delimited ASCII file format:

1) Machine Model, Type, and Serial/Machine Number
2) Roller Drum Dimensions (Width and Diameter)
3) Roller and Drum Weights
4) File Name
5) Date Stamp
6) Time Stamp
7) RTK based GPS measurements showing Northing, Easting, and Elevation
8) Roller Travel Direction (e.g., forward or reverse)
9) Roller Speed
10) Vibration Setting (i.e., On or Off)
11) Vibration Amplitude
12) Vibration Frequency
13) Surface Temperature
14) Compaction Measurement Value

Ensure that the roller's onboard display will furnish color-coded GPS based mapping showing number of roller passes, surface temperature, vibration frequency, vibration amplitude, and the MV on a computer screen in the roller operators cab. Provide displayed results to the Engineer for review upon request.

C. Local GPS Base Station
Provide a real time kinematic global positioning system (RTK GPS) to acquire northing, easting, and elevation data used in mapping of IC measurements. Ensure the system has the capability to collect data in an established project coordinate system. Furnish a local GPS base station used for broadcasting differential correction data to the rollers with a tolerance less than 0.1 ft in the vertical and horizontal.

D. Training

1. Preconstruction (classroom)
Make available all personnel responsible for roller operations to attend a one-day classroom training on IC. Training will be provided by Iowa State University research personnel and scheduling coordinated by the Engineer. Classroom training will involve both the Contractor's and Engineer's personnel.

2. Field (prior to and during compaction operations)
Provide two working days of field training by the IC equipment manufacturer to roller operators and Engineer's personnel.

E. Geotechnical Mobile Lab Parking
Provide the Engineer an all weather access, parking for the Iowa State University Geotechnical Mobile lab trailer (8 feet by 44 feet), and parking for 3 vehicles at the HMA plant site or agreed upon alternative location. The lab trailer will be furnished and operated by Iowa State University which will be under contract with the Contracting Authority to perform IC-HMA research.

090048.03 Construction

A. Roller Verification/Repeatability Testing
Construct periodic test strips under controlled roller operations for evaluating IC roller measurement errors. Coordinate with the Engineer and Iowa State University research personnel at least one day in advance of testing for IC roller repeatability evaluation. Test strip construction will require four to six roller passes on a 200 feet long strip of intermediate course by one roller width area under controlled roller operating conditions (i.e., constant speed, vibration amplitude, and frequency). The IC measurements obtained in the same area for several repeated passes will be used to assess the measurements errors. The results will be used for research purposes to validate the manufacturer claims for the IC measurement reliability. It is anticipated that repeatability test strips will be identified during the course of the project. The test strip areas can be designed within the production compaction areas.

B. Roller Operations
Operate the IC roller according to manufacturer's recommendations to provide reliable and repeatable measurements. Keep vibration frequency and amplitude constant during roller opertations for comparing successive passes. Changes in frequency and amplitude influence MVs. Permitted variation in vibration frequency is ± 125 vibrations per minute. Maintain rolling speed to provide a minimum of 10 impacts per linear foot and within ± 0.5 miles per hour during measurement passes. Speed fluctuations influence the MVs and are not permitted outside this range during measurement passes. Record IC-HMA roller operations forward and reverse directions. It is anticipated that MVs will be affected by rolling direction and therefore the output data fields shall indicate rolling direction. Check and recalibrate, if necessary, IC equipment at the beginning of each workday.

C. Equipment Breakdowns
In the event of IC roller breakdowns/IC system malfunctions/GPS problems, the Contactor may operate with conventional rolling operations, but IC data shall be collected and provided for a minimum 80% of the project surface and intermediate HMA quantity.

D. Data submittal
Furnish to the Engineer an electronic file in ASCII file format with information listed under Article SP-090048.02, B. As a minimum the file transfer shall occur immediately following the final compaction operations on each working day. The Engineer may request data any time during compaction operations.

090048.04 Method of Measurement
None. Lump sum item.

090048.05 Basis of Payment

A. Payment for Intelligent Compaction-HMA will be the lump sum contract price.

B. Payment is full compensation for all work associated with providing IC equipped rollers, transmission of electronic data files, two copies of IC roller manufacturer software, training, and preparing and maintaining work space for Iowa State University's IC trailer and associated parking.

C. Delays due to GPS satellite reception of signals to operate the IC equipment or IC roller breakdowns will not be considered justification for contract modifications or contract extensions.

Appendix D: Intelligent Compaction Brief — I-29 Pavement Foundation Layer Construction Demonstration Project

INTELIIGENT COMPACTION BRIEF December 2010

Iowa DOT Intelligent Compaction Research and Implementation – I-29 Pavement Foundation Layer Construction Demonstration Project

PROJECT DATE/DURATION
Aug. 31 to Sep. 2 and Sep. 9, 2009

RESEARCH PROJECT TITLE
Iowa DOT Intelligent Compaction Research and Implementation – Phase I

SPONSOR
Iowa Department of Transportation

RESEARCH TEAM
David J. White, Ph.D.
Pavana KR. Vennapusa, Ph.D.
Heath Gieselman, M.S.

PRINCIPAL INVESTIGATOR
David J. White, Ph.D.
Assoc. Prof., Civil, Construction, and Environmental Engineering Dir.,
Earthworks Engineering Research Center
Iowa State University
515-294-1463
djwhite@iastate.edu

MORE INFORMATION
www.eerc.iastate.edu

Earthworks Engineering Research Center
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
www.eerc.iastate.edu

The Earthworks Engineering Research Center (EERC) is co-located and administered by the Center for Transportation Research and Education (CTRE) at Iowa State University. The mission of the EERC is to lead accelerated development and deployment of earth mechanics and geo-construction technology advancements for improved, cost-effective earth foundations.

EERC
EARTHWORKS ENGINEERING RESEARCH CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

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Objectives

The objective of this field demonstration project was to evaluate the compaction meter value (CMV) system—an intelligent compaction (IC) technology on the Volvo SD116DX smooth drum vibratory roller—for use in quality control (QC) and quality assurance (QA) during construciton of the pavement foundation layer. The following research tasks were established for the study:

- Develop correlations between CMV and various conventionally used in situ point measurement values (point-MVs) in earthwork QC/QA practice.
- Evaluate the advantages of using the technology for production compaction operations.
- Obtain data to evaluate future IC specifications.
- Develop content for future educational and training materials for Iowa DOT and contractor personnel.

Project Description

This demonstration project was located on I-29 in Monona County, Iowa. The project involved reconstructing the pavement foundation layers (base, subbase, and subgrade) of the existing Interstate highway on the northbound and southbound lanes on I-29 in Harrison and Monona Counties from just south of county road F-20 to just north of I-75. The existing subgrade layer was undercut to about 0.30 to 0.60 m below the existing grade. The exposed subgrade in the excavation was scarified and recompacted. The excavation was then replaced with a 0.30 to 0.45 m thick recycled asphalt ("special backfill subgrade treatment") subbase layer and a 0.15 m thick recycled portland cement concrete (RPCC) base layer. Crushed limestone material was also used for the subbase layer in some areas.

The Volvo SD116DX smooth drum vibratory roller used on this project was equipped with a compaction meter value (CMV) system and global positioning system (GPS) outfitted by Trimble, Inc.

The onboard display unit on the machine consisted of a Trimble® CB430 unit for real-time display of IC measurements (Figure 1). A total of 11 test beds were constructed and tested as part of this project. Compaction on the test beds was achieved using the Volvo IC roller. Three in situ testing methods (Figure 2) were used in this project to evaluate the in situ soil compaction properties and obtain correlations with CMV: (a) Humboldt nuclear gauge (NG) to measure soil dry unit weight (γ_d) and moisture content, (b) Zorn light weight deflectometer (LWD) setup with 300 mm plate diameter to measure elastic modulus (ELWD-Z3), and (c) dynamic cone penetrometer (DCP) to determine California bearing ratio (CBR).

Figure 1. Volvo SD116DX smooth drum vibratory roller (top), and the on-board Trimble CB430 display (bottom)

Figure 2. Nuclear gage (top left), dynamic cone penetrometer (top right), light weight deflectometer (bottom)

The Volvo machine consisted of low amplitude and high amplitude settings. In low amplitude setting the theoretical amplitude was a = 1.50 mm at frequency f = 34 Hz. In high amplitude setting the theoretical amplitude was a = 1.85 mm at frequency f = 30 Hz. the actual amplitude was measured and reported in the output. The data output contained the following information: (a) GPS position (i.e., northing/easting/ elevation), (b) machine speed, (c) CMV, (d) resonant meter value (RMV), (e) frequency and amplitude, (f) machine gear (forward/reverse), and (g) vibration setting (on/off).

Test Results and Analysis

Calibration Test Beds

One calibration test bed each for each material (subgrade, subbase, and base) was constructed as part of this project (Figure 3). CMV and in situ point-MVs obtained from multiple roller passes on subgrade, recycled asphalt subbase, and RPCC base layer test beds were used to develop compaction curves, as shown in Figure 4. Results indicated that the CMV, E_{LWD-Z3}, CBR, and γ_d measurements on the subbase layer are higher than on the subgrade layer.

Figure 3. Preparation of calibration test beds

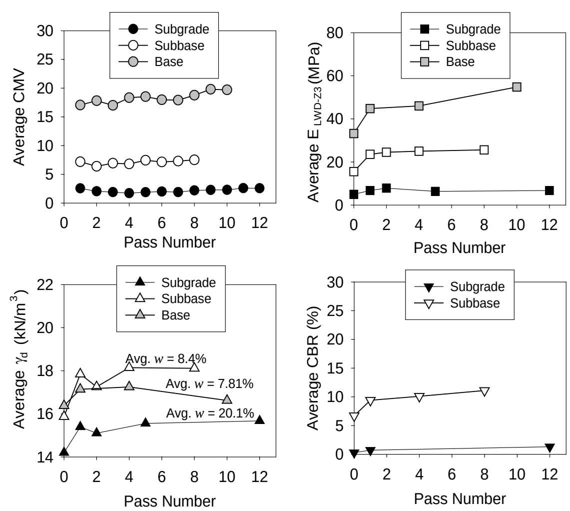

Figure 4. Average (per pass) CMV, E_{LWD-Z3}, γ_d, and CBR compaction curves for subgrade, subbase, and base layers

The CMV and E_{LWD-Z3} values on the base layer were higher than on the subbase layer. The γ_d measurements were slightly lower on the base layer than on the subbase layer. The average CMV did not change considerably with increasing pass number on the three layers. The average E_{LWD-Z3} values on the subgrade and subbase layers increased up to pass 2 and then remained constant up to the final compaction pass. The average E_{LWD-Z3} on the base layer increased from pass 0 to 1, remained constant up to pass 4, and then increased up to pass 10. The average γ_d on all three layers increased from pass 0 to 1 and then generally remained at the same level up to the final pass. Correlations from these calibration test beds yielded correlations with $R^2 < 0.5$ due to the narrow range of the measurements. The correlations calculated by combining results from multiple test beds are presented below.

Production Test Beds

A total of seven production area test beds were constructed and tested as part of this study. Production area maps were obtained by creating two to three roller maps (Figure 5) at different amplitude settings (i.e., low and high amplitude). The in situ point-MV locations were selected based on the roller map, i.e., at locations with relatively high, medium, and low CMV. Figure 6 shows an example of production test bed data (CMV in low and high amplitude settings) from subgrade and overlying special backfill subbase layers with DCP-CBR profiles at three selected locations.

Results indicate that the CMV measurements are influenced by vibration amplitude. CMV measurements on the subgrade were on average about 1.1 to 1.3 times greater at high-amplitude setting (i.e., a = 2.00 mm) than at low-amplitude setting (i.e., a = 1.50 mm). Similarly, CMV measurements of the subbase and base layers were on average about 1.2 to 1.5 times greater at high-amplitude setting than at low-amplitude setting. This is likely due to potential differences in the magnitude of stresses applied to the materials by the roller drum under different amplitude settings. Figure 7 shows a CMV map on an on-board display highlighting a box culvert location with a high CMV.

Regression Analysis Results

Based on data obtained from multiple test beds on this project, regression relationships between CMV (in low- and high-amplitude settings) and point-MVs were developed, as shown in Figure 8. Nonlinear exponential relationships showed the best fit for CMV vs $E_{LWD\text{-}Z3}$ MVs with R^2 = 0.66 to 86. Relatively weak regression relationships with R^2 = 0.12 to 0.18 was observed for CMV vs CBR. No statistically significant relationship was found for CMV vs. γ_d.

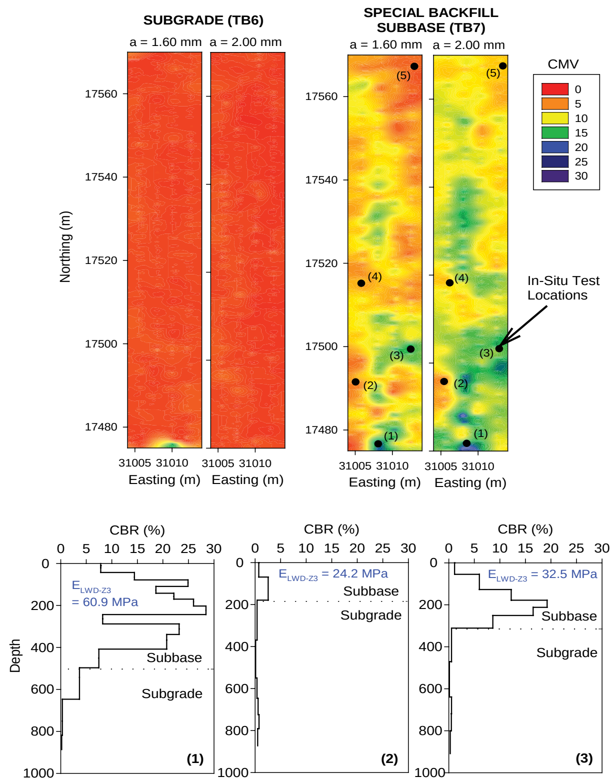

Figure 6. Spatial comparison of a subgrade layer CMV map overlain by a special backfill subbase layer CMV map and DCP-CBR profiles at three selected locations

Figure 5. Mapping operations on a production base layer test production test bed

Figure 7. CMV map on an on-board display highlighting a box culvert location with a high CMV

Repeatability Analysis Results

The error associated with the repeatability of IC is believed to be one source of scatter in relationships with in situ point-MVs. One challenge for evaluating the repeatability of IC measurements is that the data points obtained from different passes are not collected at the exact same location. To overcome this problem on this project, the data were processed in such a way that an average data point was assigned to a preset grid point along the roller path. The grid point was set at 0.3 m along the roller path, which represented an average of IC-MVs that falls within a window of size 0.15 m in the forward and backward directions (the actual data were reported every 0.15 to 0.3 m). Repeatability analysis was performed on measurements obtained from compaction passes on subgrade, subbase, and base layer calibration beds (Figure 9) under identical operating conditions (i.e., same amplitude, nominal speed, and direction). The CMV measurement error was quantified by taking pass count and measurement location into account as random effects in a two-way analysis of variance (ANOVA). For this data set, the CMV measurement error was about ≤ 1.1 for low-amplitude settings at a nominal operation speed of about 4 km/h.

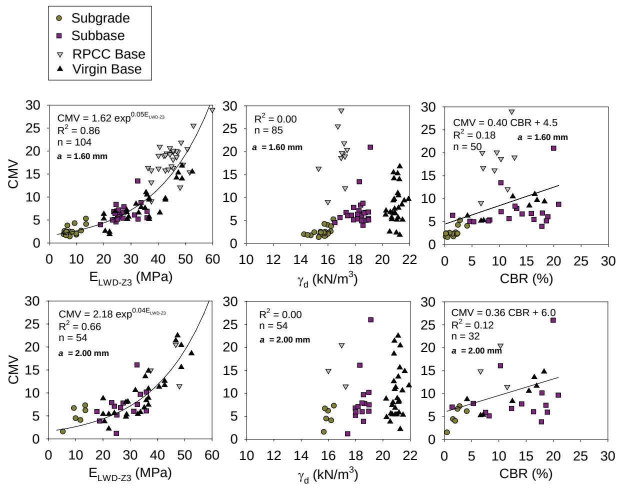

Figure 8. Empirical correlations between CMV and in situ point-MVs

Summary of Key Findings

- Data from calibration strips indicated that the CMV, $E_{LWD\text{-}Z3}$, CBR, and γ_d measurements on the recycled asphalt subbase layer were relatively higher than on the subgrade layer. The CMV and $E_{LWD\text{-}Z3}$ values on the RPCC base layer were higher than on the subbase layer. The γ_d measurements were slightly lower on the RPCC base layer than on the recycled HMA subbase layer.
- Correlations developed from this project yielded nonlinear exponential relationships between CMV and $E_{LWD\text{-}Z3}$, with R^2 = 0.66 and 0.86 for low- and high-amplitude settings, respectively. Relatively weak regression relationships with R^2 < 0.2 were observed between CMV and CBR. No statistically significant relationship was found between CMV and γ_d.
- CMV maps obtained on the subbase and the overlaid RPCC base layers indicate that "soft" and "stiff" zones in the subbase layer maps are reflected on the RPCC base layer maps.
- CMV maps were able to effectively delineate "soft" and "stiff" zones effectively.
- CMV measurements were on average about 1.1 to 1.5 times greater at high-amplitude setting than at low-amplitude setting. This is likely due to potential differences in the magnitude of stresses applied on the materials by the roller drum under different amplitude settings.
- The CMV measurement error was about ≤ 1.1 for low-amplitude settings at a nominal machine speed of about 4 km/h.

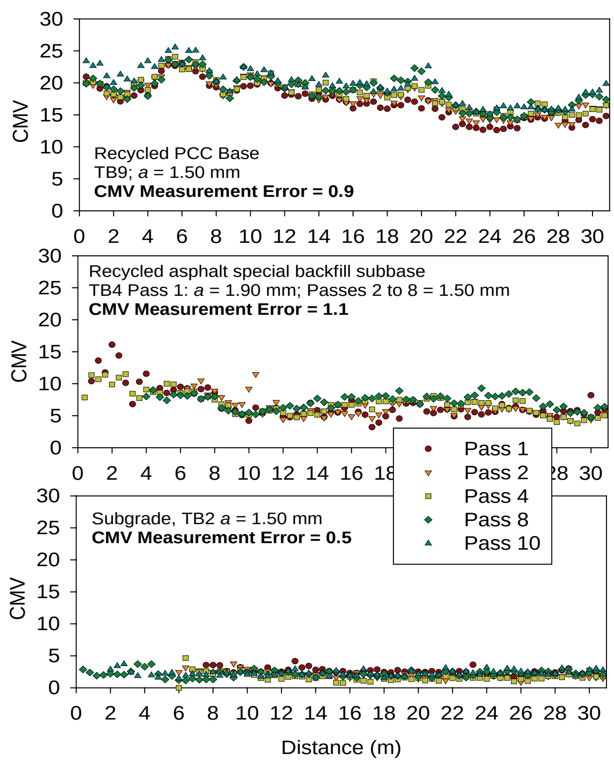

Figure 9. CMV measurements from multiple passes on subgrade, subbase, and base layers

Compaction Roadeo Field Demonstration

Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform (SHRP2 R02)

SHRP2 STRATEGIC HIGHWAY RESEARCH PROGRAM

The Strategic Highway Research Program (SHRP) sponsored a research project titled "Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform – SHRP2 R02". As part of this project, a *Compaction Roadeo* is planned to conduct field demonstrations of different compaction technologies.

This document provides a brief background of the SHRP2 R02 project, objectives of the field demonstrations, overview of the compaction equipment, field testing plans/schedule, and supporting needs from the hosting state department of transportation (DOT).

SHRP2 R02 Project Background

The SHRP2 R02 project encompasses a broad spectrum of geotechnical and geoconstruction technologies to achieve the SHRP2 renewal strategic objectives of rapid renewal, minimal disruption, and long-lived facilities, focusing on three "elements":

(1) construction of new embankments and roadways over areas of unstable soils,
(2) widening and expansion of existing roadways and embankments, and
(3) improvement and stabilization of the support beneath the pavement structure.

A total of 49 technologies were identified for the three elements, including several compaction technologies that fall under element 3.

Compaction Roadeo Demonstration

A comprehensive review of literature, a detailed assessment of several technical obstacles that interfere with more widespread use, and evaluation of mitigation strategies/ action items in terms of benefit-to-cost (B/C) ratio for each of the element 3 technologies were recently completed. Three compaction technologies (Table 1): Rapid Impact Compaction (RIC), Intelligent Compaction (IC), and High Energy Impact Roller (IR), received high B/C ratio. One of the major obstacles for wide-spread implementation of RIC, IC, and IR technologies is identified as lack of well-documented and accessible case histories with benefits related to construction cost, time, efficiency, and effectiveness in consistently obtaining design properties, of using these technologies compared to traditional compaction methods. Conducting *Compaction Rodeo* field demonstration projects is as an effective mitigation strategy to overcome this obstacle.

The main objective of the field demonstrations is to develop detailed case history information for different material and subsurface conditions (i.e., lift thicknesses, etc.) comparing the relative compaction efficiency, time, and cost using the different compaction methods (RIC, IR, IC, and traditional). In-situ testing measuring soil density, strength, and stiffness properties will be conducted and detailed field notes (keeping track of time, cost and efficiency) will be obtained to develop comparison information. Specific research objectives are to: (a) provide information related to pavement design inputs for the subgrade, base, and subbase layer properties resulting from using different compaction methods, (b) provide improved methods to effectively design the compaction process (e.g., spacing and pattern for RIC and IR compaction), and (c) develop products that will contribute to guidance and selection system such as photos and videos, detailed case history information, cost information, QA/QC methods, and various attributes of specifications. The field demonstrations will also contribute to elements 1 and 2 applications as compaction is a common element in embankment construction.

Table 1. *Applications for compaction equipment*

Compaction Machinery Type	Soil Type Applicability: Cohesive	Soil Type Applicability: Granular	Compaction Depth	Potential Applications: General Earthwork (Existing/New Fill)	Construction of Working Platform	Pavement Found. Stabilization	QC/QA Monitoring System	Concrete Rubblization
Rapid Impact Compactor (RIC)	?	✓	> 1 m	✓	✓	?	✓	✓
High Energy Impact Roller (IR)	✓	✓	~ 1 m	✓	✓	✓	✓	✓
Pad Foot with IC/CCC	✓		< 0.5 m	✓	✓		✓	
Smooth Drum with IC/CCC		✓	< 0.5 m	✓	✓		✓	

Compaction Equipment

Rapid Impact Compactor (RIC)

The RIC (Figure 1) utilizes impact forces to densify loose soil. The device is mounted to an excavator and is composed of a hydraulic piling hammer, an anvil, and an in-cab-computer. Compaction is performed by dropping the hammer drops a weight of approximately 7.5 tons from a height of approximately 4 ft onto a 5 ft diameter anvil. The in-cab-computer records the number of blows, the deflection of the ground, the total crater depth, the total energy input and the drop height. Each compaction point will receive anywhere from 10 to 100 blows. Blow rate is on the order of 40 to 60 blows per minute.

Intelligent Compaction (IC)

Intelligent companion (IC) technologies consist of machine-integrated sensors and control systems that provide a record of machine-ground interaction on an on-board display unit in real-time. With feedback control and adjustment of vibration amplitude and/or frequency and/or speed during the compaction process, the technology is referred to as intelligent compaction (IC). Without the vibration feedback control system the technology is commonly referred to as continuous compaction control (CCC). IC and CCC systems have evolved over the past 30 years to include a variety of different measurement techniques and global positioning system (GPS) based documentation systems (Figure 2).

High Energy Impact Roller (IR)

The IR's are non-circular shaped tow behind solid steel molds that typically vary in weight from about 8 to 12 tons (Figure 3). The impact compaction energy is transferred to the soil by means of lifting and falling motion of the non-circular rotating mass. The rollers are pulled at a relatively high speeds (typically from 10 to 12 km/h) to generate a high impact force that reportedly can densify material to depths greater than 1 m.

Figure 1. *The Rapid Impact Compactor (Courtesy of GeoStructures, Inc.)*

Figure 2. *Intelligent Compaction Rollers*

Figure 3. *Impactor 2000 "square" impact roller (Courtesy of Impact Roller Technology, Nebraska)*

Testing Equipment/Facilities

Iowa State University's Geotechnical Mobile laboratory equipped with various laboratory and in-situ testing methods and a KUAB falling weight deflectometer, and deep penetration testing methods (such as standard penetration test (SPT) and cone penetration test (CPTU)) will be utilized in characterizing the compacted fill materials.

Field Schedule

The field demonstration will be conducted in 7 to 8 consecutive days at the selected project site. The first day will involve setup of equipment, training on use of the equipment, discussion of the test plan with state DOT and contractor personnel, selection of test section locations, etc. Laboratory testing to characterize the on-site materials will take about one to two days. Field testing will take about four to five days on various test sections. One day at the end of the project will be dedicated for an open house to share the project results.

State DOT Responsibilities

We request interested state DOTs assist the research team in identifying potential project sites and coordinating the work with the contractor. Target dates for completing this work are between now and April 15, 2011. We anticipate the contractor will provide necessary embankment material, equipment and operators to prepare a few test sections. The test sections will typically be 100 to 500 ft long and can be part of normal production work on the project to minimize extra work. Preparation of a few test sections may involve material placement, scarification, grading, and moisture conditioning. The compaction equipment, operators, and all related testing work will be provided by the research team. The results from the test sections are solely for research purposes, and will not be used for approval or rejection of the materials or test sections. A detailed test plan will be provided when the project site is selected. Thank you for considering this request.

Contact
David J. White, Ph.D.
Associate Professor
djwhite@iastate.edu
(515) 294-1463(O)
(515)-290-1080 (M)

IOWA STATE UNIVERSITY
EERC
EARTHWORKS ENGINEERING

Appendix F: Intelligent Compaction Technical Publications

Journal and Conference Papers (organized by publication date)

1980

1. Forssblad, L. (1980). "Compaction meter on vibrating rollers for improved compaction control", *Proc., Intl. Conf. on Compaction*, Vol. II, 541–546, Paris.
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7. Yoo, T., and Selig, E. (1980). "New concepts for vibratory compaction of soil", *Proc., Intl. Conf. on Compaction*, Vol. II, 703–707,Paris.

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47. *I-35 HMA PAVEMENT CONSTRUCTION PROJECT, OKLAHOMA CITY, OKLAHOMA [[Commuri, S. (2010). *Intelligent Asphalt Compaction Analyzer – Phase I Report*, Highways for LIFE Technology Partnerships Programs, FHWA, Washington, D.C.]
48. *US77 HMA PAVEMENT CONSTRUCTION PROJECT, NEAR NOBLE, OKLAHOMA [Commuri, S. (2010). *Intelligent Asphalt Compaction Analyzer – Phase I Report*, Highways for LIFE Technology Partnerships Programs, FHWA, Washington, D.C.]
49. *HMA PAVEMENT CONSTRUCTION PROJECT, TECUMSEH ROAD, NORMAN, OKLAHOMA [Commuri, S. (2010). *Intelligent Asphalt Compaction Analyzer – Phase I Report*, Highways for LIFE Technology Partnerships Programs, FHWA, Washington, D.C.]

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50. *RESEARCH TEST SECTIONS, ODESSA, DELAWARE [Tehrani, F.S., and Meehan, C.K. "Continuous compaction control: Preliminary data from a Delaware case study." *Eighth Intl. Conf. on the Bearing Capactiy of Raods, Railways, and Airfields (BCR2A'09)*, June 29–July 2, Champaign, Illinois.]
51. *US340 HMA IC FIELD DEMONSTRATION, FREDERICK, MARYLAND [Chang, G., Xu, Q., Horan, B., Michael, L. (2009). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – US340, Frederick, Maryland HMA IC Demonstration*, Report submitted to FHWA, September.]
52. *PARK & RIDE PARKING LOT, HMA IC FIELD DEMONSTRATION, CLAYTON COUNTY, GEORGIA [Chang, G., Xu, Q., Horan, B., Michael, L. (2009). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – Clayton County, Georgia HMA IC Demonstration*, Report submitted to FHWA, March.]
53. *US212, NEW YORK FHWA IC POOLED FUND STUDY DEMONSTRATION [White, D.J., Vennapusa, P., Gieselman, H., Zhang, J., Goldsmith, R., Johanson, L., Quist, S. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) - NY IC Demonstration Field Project*, EERC Publication ER10-01, Report submitted to The Transtec Group, FHWA, January.]

54. *US84, MISSISSIPPI FHWA IC POOLED FUND STUDY DEMONSTRATION [White, D.J., Vennapusa, P.., Gieselman, H., Fleming, B., Quist, S., Johanson, L. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – Mississippi IC Demonstration Field Project*, ER10-03, Report submitted to The Transtec Group, FHWA, January.]

55. *I29, MONONA COUNTY, IOWA – PAVEMENT FOUNDATION LAYER CONSTRUCTION [White, D.J., Vennapusa, P., Gieselman, H. (2010). *Iowa DOT Intelligent Compaction Research and Implementation – Phase I*, ER-10-06, Final Report, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa, December.]

56. *US30, COLO, IOWA – EMBANKMENT CONSTRUCTION [White, D.J., Vennapusa, P., Gieselman, H. (2010). *Iowa DOT Intelligent Compaction Research and Implementation – Phase I*, ER-10-06, Final Report, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa, December.]

57. *US218, CORALVILLE, IOWA, COLO, IOWA – HMA OVERLAY CONSTRUCTION [White, D.J., Vennapusa, P., Gieselman, H. (2010). *Iowa DOT Intelligent Compaction Research and Implementation – Phase I*, ER-10-06, Final Report, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa, December.]

58. *GEOSYNTHETIC STABILIZED SUBBASE TEST SECTIONS, WEIRTON, WEST VIRGINIA [White, D.J., Gieselman, H., Douglas, S., Zhang, J., Vennapusa, P. (2010). *In-Situ Compaction Measurements for Geosynthetic Stabilized Subbase: Weirton, West Virginia*. ER10-05, Prepared by the Earthworks Engineering Research Center at Iowa State University, Report submitted to Tensar, Inc.

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60. **HWY 30, HARRISON COUNTY, IOWA – HMA OVERLAY CONSTRUCTION [White, D.J., Vennapusa, P., Gieselman, H., Harland, J., Quist, S. (2011). *Iowa DOT Intelligent Compaction Research and Implementation – Phase I*, Final Report, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa, (in preparation).]

61. **HWY 20, IDA COUNTY, IOWA – HMA OVERLAY CONSTRUCTION [White, D.J., Vennapusa, P., Gieselman, H., Harland, J., Quist, S. (2011). *Iowa DOT Intelligent Compaction Research and Implementation – Phase I*, Final Report, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa, (in preparation).]

62. *US12, MARMARTH, NORTH DAKOTA FHWA IC POOLED FUND STUDY DEMONSTRATION [White, D.J., Vennapusa, P., Gieselman, H., Zhang, J., Eidem, M. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – North Dakota IC Demonstration Field Project*, ER10-08, Report submitted to The Transtec Group, FHWA, November.]

63. *SR-25, WEST LAFAYETTE, INDIANA FHWA IC POOLED FUND STUDY DEMONSTRATION [White, D.J., Vennapusa, P., Gieselman, H., (2010). *Accelerated*

Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – Indiana IC Demonstration Field Project, Report submitted to The Transtec Group, FHWA (in preparation)].

64. *US52 HMA IC FIELD DEMONSTRATION, WEST LAFAYETTE, INDIANA [Chang, G., Xu, Q., Horan, B., Michael, L. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – US52 West Lafayette, Indiana HMA IC Demonstration*, Report submitted to FHWA, March.]
65. *FM1281 HMA IC FIELD MINI DEMONSTRATION, EL PASO, TEXAS [Chang, G., Xu, Q., (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – FM1281, El Paso, Texas, HMA IC Demonstration*, Report submitted to FHWA, June.]
66. *IH39 HMA IC FIELD DEMONSTRATION, MOSINEE, WISCONSIN [Chang, G., Xu, Q., Horan, B., Michael, L. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – IH39, Mosinee, Wisconsin HMA IC Demonstration*, Report submitted to FHWA, June.]
67. *US219 HMA IC FIELD DEMONSTRATION, SUMMERHILL, PENNSYLVANIA [Chang, G., Xu, Q., Horan, B., Michael, L. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – US219, Summerhill, Pennsylvania HMA IC Demonstration*, Report submitted to FHWA, October.]
68. *I-66 HMA IC FIELD DEMONSTRATION, FAUQUIER COUNTY, VIRGINIA [Chang, G., Xu, Q., Horan, B., Michael, L. (2010). *Accelerated Implementation of Intelligent Compaction Monitoring Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials TPF-5(128) – I-66, Fauquier County, Virginia HMA IC Demonstration*, Report submitted to FHWA, October.]
69. *STH80 SUBGRADE, BASE, AND HMA RECONSTRUCTION AND WIDENING PROJECT, NORTH OF HIGHLAND, WISCONSIN [Quintus, V.L.H., Rao, C., Bhattacharya, B., Titi, H., English, R. (2010). *Evaluation of Intelligent Compaction Technology for Densification of Roadway Subgrades and Structural Layers*, WHRP Project No. 0092-08-07 (Draft Final Report), Prepared by Applied Research Associates and University of Wisconsin at Milwaukee, November.]
70. *STH18 SUBGRADE AND BASE RECONSTRUCTION PROJECT, WEST OF JEFFERSON, WISCONSIN [Quintus, V.L.H., Rao, C., Bhattacharya, B., Titi, H., English, R. (2010). *Evaluation of Intelligent Compaction Technology for Densification of Roadway Subgrades and Structural Layers*, WHRP Project No. 0092-08-07 (Draft Final Report), Prepared by Applied Research Associates and University of Wisconsin at Milwaukee, November.]
71. *US45 HMA OVERLAY PROJECT, NEAR EDEN, WISCONSIN [Quintus, V.L.H., Rao, C., Bhattacharya, B., Titi, H., English, R. (2010). *Evaluation of Intelligent Compaction Technology for Densification of Roadway Subgrades and Structural Layers*, WHRP Project No. 0092-08-07 (Draft Final Report), Prepared by Applied Research Associates and University of Wisconsin at Milwaukee, November.]

Appendix G: Workshop Photos

Appendix H: Workshop Evaluation Comments

Technology Transfer Intelligent Compaction Consortium (TTICC)

Summary of Evaluation Forms

December 14-15, 2010

Please rate the following by circling a number between 1 and 5.

	Very Good		Okay		Needs Improvement
1. Topics covered	1	2	3	4	5
Average score: 1.25					
2. Organization of the program	1	2	3	4	5
Average score: 1.25					
3. Speakers knowledgeable	1	2	3	4	5
Average score: 1.17					
4. Facilities were accommodating	1	2	3	4	5
Average score: 2.08					
5. Program met expectations	1	2	3	4	5
Average score: 1.33					

6. What were the most worthwhile parts of this program?

- Digesting the worthiness of the technology. It was helpful to be surrounded by proponents who were trustworthy and technically competent.
- Proposed action items discussion.
- Development of action plans from breakout sessions.
- Laying out the road map. Discussion amongst the states about the technology.
- Developing action items.
- Breakout sessions. Action items.
- The open discussion, informal format, and the vast amounts of content.
- Networking; finding out what other states were doing.
- Presentations.
- New technology, QC, extra field condition info.

7. What were the least worthwhile parts of this program?

- Day two's summary of breakout sessions. It took an hour and could have been presented on a piece of paper. Plus we had near consensus between groups so it was redundant.
- None.
- Synthesis of QC/QA spec's.

- Breakout session got off topic at times.
- Review past IC workshop.
- None.
- None.

8. What other topics were you hoping would be included in this program?

- Not a topic, but it would have been very nice for TTICC to have paid for alcohol when we went to dinner. It was consumed anyway and aided group camaraderie—so why not pay?
- Equipment demonstration. Feedback of the analysis; sample of the specification (SSP) and how to pay for the pilot study.
- More detail on how IC technically works, however, Dr. White mentioned that manufacturers have documented their processes. I've presented IC at conferences/ meetings and would like this info to better answer questions.
- Some people don't know about the technology, so an explanation of the differences amongst manufacturers may help.
- Hearing about other states' problems with IC.
- Did not have any expectations.
- Contractor/industry input (state of technology development).
- More case study.
- Technical explanation of the measurements and workings of equipment.

9. Do you have any suggestions for future workshop topics?

- Go over some summaries of studies. Get some consensus about study results and present them in the seminar in an easy to digest way. Maybe I just didn't understand a portion of what was presented (graphs, etc.) in the current seminar.
- Software demonstration. Equipment demonstration.
- Include contractors and equipment manufacturers.
- Technical discussion about how the different systems work.
- Once states have completed demo projects, hear about +'s and –'s.
- I would like to see the focus be balanced equally between asphalt and soil. I felt the focus was predominantly on soil.
- We beat that one up already.
- See #8.
- Demo's.
- See #8.

Thank you!

Appendix H: Geotechnical Mobile Lab Brochure

MOBILE GEOTECH RESEARCH LAB
Made Possible by Partnerships

Hydraulic tube sampling attachment

Advancing Intelligent Construction

Iowa State University's Geotechnical Mobile Lab helps researchers conduct projects in Iowa and beyond. The lab supports research conducted through the Center for Transportation Research and Education's Earthworks Engineering Research Center (EERC) and the Department of Civil, Construction, and Environmental Engineering's Geotechnical Engineering Division.

Research Focus

Geotechnical engineering focuses on soil mechanics, earth structures, foundations, and retaining structures. Iowa State University geotechnical researchers define and prioritize geotechnical problems and, through an understanding of these problems, develop applicable solutions that result in increased value through better life-cycle performance.

Vision for the Lab

Geotechnical construction projects will be built with specifications and processes that allow maximum efficiency and creativity on the part of the contractor, use acceptance criteria that ensure responsible use of public funds, and maximize value by increasing the performance life of roadways.

Objectives for the Lab

- Better understand the engineering properties of soils that relate to performance in highway construction and have a high degree of reliability for agencies and contractors.
- Improve earthwork construction quality and efficiency through the use of current and emerging construction equipment and intelligent construction technologies.
- Develop improved laboratory and field testing technologies and procedures for verification testing.
- Test and field measure the soil properties that relate to performance and use this knowledge to develop methods of quality control/quality assurance (QC/QA) for geotechnical applications.
- Provide field training opportunities to contractors, public agency personnel, and engineering students.

Benefits Being Sought

- Increased productivity and efficiency
- Reduced construction costs
- More responsible use of public investments
- Greater reliability
- Improved performance

Support/Tow Vehicle Details

- Freightliner M2 106
- Allison automatic transmission
- Mercedes Benz 300 hp diesel engine
- Air-brake equipped
- Rear air suspension
- Extended cab
- 16 ft steel flatbed with gooseneck ball hitch
- Six side toolboxes for securely stowing field equipment
- 2,500 watt, 12 v DC/110 v AC inverter
- 50 gal water tank with electric demand pump
- 40 gal diesel fuel nurse tank with pump
- Safety beacon
- Kawasaki 3010 diesel mule ATV for onsite transportation and testing
- ATV ramps and tie-downs
- Plate load reaction frame mounted under truck frame
- Hydraulic tube sampling attachment

Lab Trailer Details

- 44 ft long all-aluminum, insulated trailer
- 36 ft x 8 ft 6 in. lab area divided into three rooms
- 7 ft 6 in. interior height
- Gooseneck: 20 kw diesel electric generator on air suspension; 50 gal diesel fuel tank; 100 gal water tank
- Twin 10,000 lb capacity axels with air ride suspension
- Air brake system
- External front and rear electric (110 v) and water connections
- 110 v, 220 v, and 12 v DC electric systems
- Three room heaters and air conditioners
- Two large exhaust fans
- Two floor drains
- Four hydraulic leveling jacks
- Hot and cold water
- Stainless steel counter tops
- Rubberized floor coating
- Two Lista tool cabinets
- Twelve equipment tie-downs
- Conference/work area with 32 in. x 52 in. table and four chairs
- 64 in. x 28 in. desk area
- Satellite Internet
- Video presentation screen

Lab Equipment

- Pine "Brovold" gyratory compactor
- Proctor "Ploog" soil compactor
- Endecotts EFL 2000 vibratory sieve shaker
- Certified sieves for particle size analysis
- Hobart 12-quart mixer
- Humbolt rapid soil grinder
- Syntron vibrating table with molds for relative density testing of cohesionless soils
- Two Fisher Isotemp ovens
- Refrigerator
- Microwave oven
- Geocomp LoadTrac II with two FlowTrac II pumps and additional equipment for resilient modulus testing
- Triaxial and resilient modulus cell for 2.8 in. and 4 in. sample testing
- Triaxial and resilient modulus cell for 6 in. sample testing consolidation cell (2.5 in.)
- HP laptop computer
- Soilmoisture PM 300 psi air compressor
- Ohaus Pro Series balances (4,100.00 g and 32,000.0 g)
- Hydrometer set
- Liquid and plastic limits testing equipment
- Davis Vantage Pro weather station with Weatherlink datalogger
- Fully equipped with tools and laboratory sample preparation equipment

Field Equipment

- Kessler dynamic cone penetrometer
- Plate load testing equipment
- Panasonic Toughbook
- Analytical Spectral Devices Agrispec portable near-infrared spectrometer
- Lightweight falling weight deflectometer
- Humbolt nuclear density gauge
- Clegg hammer
- TDR testing equipment
- Trimble GPS system model 851 and 881
- Humbolt Geogauge

Geocomp LoadTrac II | Geocomp FlowTrac II pumps | Syntron vibrating table | Proctor "Ploog" soil compactor | Pine "Brovold" gyratory compactor | Hobart 12-quart mixer | Endecotts EFL 2000 sieve shaker | Humbolt rapid soil grinder | Video presentation screen | Proctor "Ploog" soil compactor | Liquid and plastic limits testing equipment