Report of the
Workshop on Intelligent Construction for Earthworks

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EERC EARTHWORKS ENGINEERING RESEARCH CENTER

IOWA STATE UNIVERSITY Institute for Transportation

Iowa Department of Transportation

Report of the
Workshop on Intelligent Construction for Earthworks

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Preface

This document summarizes the discussion and findings of a workshop on intelligent technologies for earthwork construction held in West Des Moines, Iowa, on April 14–16, 2009. This meeting follows a similar workshop conducted in 2008. The objective of the meeting was to provide a focused discussion on identifying research and implementation needs/strategies to advance intelligent compaction and automated machine guidance technologies. Technical presentations, interactive working breakout sessions, and a panel discussion comprised the workshop. About 100 attendees representing state departments of transportation, Federal Highway Administration, contractors, equipment manufacturers, and researchers participated in the workshop.

Acknowledgments

The Earthworks Engineering Research Center (EERC) at Iowa State University of Science and Technology gratefully acknowledges the Iowa Department of Transportation (Iowa DOT) for sponsoring this workshop. Travel support for most state department of transportation (DOT) participants and support for the development of this report were made possible by the Iowa DOT.

The EERC also sincerely thanks the following individuals for their support of this workshop.

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Abbreviations

AGC	=	Associated General Contractors
AMG	=	automated machine guidance
APAI	=	Asphalt Paving Industry of Iowa
CBR	=	California bearing ratio
CCC	=	continuous compaction control
CCV	=	Sakai compaction control value; Caterpillar compaction value
CIV	=	Clegg impact value
CMV	=	compaction meter value
DCP	=	dynamic cone penetrometer
DOT	=	Department of Transportation
DTM	=	digital terrain model
EED	=	electronic engineering data
E_{FWD}	=	falling weight deflectometer elastic modulus
E_{LWD}	=	light weight deflectometer elastic modulus
E_{PLT}	=	plate load test elastic modulus
E_{SSG}	=	soil stiffness gauge elastic modulus
E_{vib}	=	BOMAG roller vibration modulus
FHWA	=	Federal Highway Administration
FWD	=	falling weight deflectometer
GPS	=	global positioning system
HMA	=	hot mix asphalt
IC	=	intelligent compaction
K	=	hydraulic conductivity
K_s	=	case/ammann roller stiffness
LWD	=	light weight deflectometer
MDP	=	Caterpillar machine drive power
NCHRP	=	National Cooperative Highway Research Program
QA	=	quality assurance
QC	=	quality control
RMV	=	resonant meter values
TDM	=	theoretical maximum density

Executive Summary

The objectives of this workshop were to update the strategies identified during the 2008 workshop; provide a collaborative exchange of ideas and experiences; share research results; increase participants' knowledge; develop research, education, and implementation initiatives for intelligent compaction (IC) and automated machine guidance (AMG) technologies; and develop strategies to move forward.

The 2½ day workshop was organized as follows:

- Day 1: Review of 2008 workshop proceedings, technical presentations on IC and AMG technologies, and participating state department of transportation (DOT) briefings.
- Day 2: Industry/equipment manufacturer presentations and breakout interactive sessions on three topic areas.
- Day 3: Breakout session summary reporting and panel discussion involving state DOT, contractor, and industry representatives.

The results of the breakout sessions on day 2 were analyzed to identify the priorities for advancement in each of the three topic areas. Key issues for each topic were prioritized by reviewing the recorder's notes in detail, finding common topics among sessions, and summarizing the participant votes. The top 10 research and implementation needs are listed in Table 3 from the report, replicated below.

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 (16)**
6. **Project Scale Demonstration and Case Histories (13)**
7. **Understanding Roller Measurement Influence Depth (13)**
8. **Intelligent Compaction Technology Advancements and Innovations (9)**
9. **Education Program/Certification Program (8)**
10. **Intelligent Compaction Research Database (8)**

The panel discussion on day 3 was mainly centered on the following five key topics:

1. Action items (state DOT, manufacturer, and contractor perspectives)
2. Additional research/development needs for manufacturer
3. Challenges
4. Strategies (state DOT perspective)
5. Education/Training

A summary of key outcomes from the panel discussion is presented in Table 6 from the report, replicated below.

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 performing 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 "gold standard" QA method for correlations with IC measurements.**
4. **Need more refinement in the technologies with respect to more user-friendly on-board interfaces for data analysis and visualization and retrofitting capabilities.**

This workshop provided a platform to exchange ideas between researchers, practitioners, and policy makers and to provide input on current state of the practice/technology. Some important outcomes from the breakout session and panel discussions are a prioritized IC road map and AMG road map with action items to move forward. A summary of key action items derived from these discussions is presented in Table 9 from the report, replicated below. Although these road maps are a good starting point, effective and accelerated implementation of these technologies will require "champions" to create opportunities.

Table 9. Action items for advancing IC road map and AMG road map

Action Items for Advancing IC Road Map and AMG Road Map

1. **Develop six case histories (technical briefs) to demonstrate the benefits of the technologies**
2. **Conduct six webinars to facilitate training and technology transfer**
3. **Create a Specifications Technical Working Group to coordinate efforts**
4. **Regularly update the Earthworks Engineering Research Center web site (www.eerc.iastate.edu)**
5. **Explore the possibility of conducting a National Highway Institute course on IC and AMG technologies**
6. **Identify current research gaps, develop problem statements for needed research, and identify key research partners**

Introduction

The Challenge

Some of the key obstacles to effectively implement new technologies in earthworks and paving construction include lack of knowledge in technical aspects, well-documented case histories demonstrating the benefits, proper education/training materials, and widely accepted specifications and standards.[1] Improvements to earthwork construction operations using new and innovative technologies, such as intelligent compaction (IC) and automated machine guidance (AMG), can potentially offer a significant return on capital investments. IC technology integrated with global positioning systems (GPS) provides 100 percent coverage of the conditions of compacted earth and hot mix asphalt (HMA) materials. AMG technology integrated with GPS links sophisticated three-dimensional (3D) design software with construction equipment and can help direct machine operations with a high level of precision. Using IC and AMG technologies shows significant potential for enhancing the abilities of state/federal agencies and contractors to construct better, faster, safer, and cheaper transportation infrastructure projects.

Workshop Objectives and Agenda

The objectives of this workshop were to update the strategies identified during the 2008 workshop; provide a collaborative exchange of ideas and experiences; share research results; increase participants' knowledge; develop research, education, and implementation initiatives for IC and AMG technologies; and develop strategies to move forward.

The workshop was held for 2½ days and was attended by about 100 participants from 16 state departments of transportation (DOTs), 10 industry/manufacturing companies, 7 contractor companies, 4 universities, the Federal Highway Administration (FHWA), the US Army Corps of Engineers, the Associated General Contractors of Iowa (AGC), and the Asphalt Paving Association of Iowa (APAI). The first day involved a review of the 2008 workshop proceedings, technical presentations on IC and AMG technologies, and briefings from participating DOTs. The second day involved industry/equipment manufacturer presentations and breakout interactive sessions on three topic areas. The third day involved breakout session summary reporting and a panel discussion involving state department of transportation (DOT), contractor, and industry representatives.

Report Organization

This report contains technical presentation slides, a summary of state DOT briefings, notes and facilitator summary reports from the breakout sessions, and a summary of the panel discussion. The complete workshop agenda is included in Appendix A, and a list of attendees is provided in Appendix B. As background information, an overview of IC and AMG technologies, a brief review of the 2008 workshop proceedings, and some guidelines for developing IC specifications (provided to participants) are provided. Appendix C is the Iowa DOT developmental specification that was provided to participants. Photos of the workshop and comments evaluating the workshop are provided in Appendices D and E, respectively. A brochure on the Geotechnical Mobile Lab is provided in Appendix F.

[1] White D.J. (2008). *Report of the Workshop on Intelligent Compaction for Soils and HMA*, Earthworks Engineering Research Center, Iowa State University, Ames, Iowa.

Background

Overview of Intelligent Compaction and Mechanistic-Based QA/QC

IC technologies consist of machine-integrated sensors and control systems that provide a record of machine-ground interaction. With feedback control and adjustment of vibration amplitude and/or frequency during the compaction process, the technology is referred to as intelligent compaction. Without the feedback control system, the technology is commonly referred to as continuous compaction control (CCC). The measurements obtained from the roller provide an indication of ground stiffness/strength characteristics and, to some extent, degree of compaction. Most of the IC/CCC technologies are vibratory-based systems developed in Europe and Japan and have been used for more than 20 years.[2, 3, 4, 5] The vibratory-based technologies have been applied to self-propelled, single smooth drum and padfoot rollers and double drum asphalt compactors. A static-based measurement technology based on machine drive power (MDP) has been recently developed for padfoot and smooth drum rollers.[6] More recently, an artificial neural network (ANN)–based measurement system has been developed for use on asphalt rollers.[7] Over the years, the technologies evolved to integrate roller measurements with GPS measurements for real-time onboard mapping and visualization capabilities. There are at least six IC/CCC systems/parameters that are summarized in the 2008 workshop report.[1] Technical presentations from the workshop with some details of these technologies are presented later in this report.

Since 2003, transportation agencies and contractors in the US have been investigating applications of IC/CCC on earthwork and HMA construction projects. Figure 1 shows seven states with IC research/demonstration projects in the US. Table 1 provides a summary of IC research/field demonstration projects in the US. A review of this project list shows limited studies[8, 9] (sponsored by Minnesota DOT) that documented results from pilot projects where IC was specified in the project specifications.

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[2] Thurner, H. and Sandström, Å. (1980). "A new device for instant compaction control." *Proc., Intl. Conf. on Compaction,* Vol. II, 611-614, Paris.

[3] Adam, D. (1997). "Continuous compaction control (CCC) with vibratory rollers," *Proc., 1st Australia – New Zealand Conf. on Environmental Geotechnics,* November, Melbourne, Australia, 245 – 250.

[4] Kröber, W., Floss, E., and Wallrath, W. (2001). "Dynamic soil stiffness as quality criterion for soil compaction." *Geotechnics for Roads, Rail Tracks and Earth Structures,* A.A.Balkema Publishers, Lisse / Abingdon/ Exton (Pa) /Tokyo, 189-199.

[5] Scherocman, J., Rakowski, S., and Uchiyama, K. (2007). "Intelligent compaction, does it exist?" *2007 Canadian Technical Asphalt Association (CTAA) Conference,* Victoria, BC, July.

[6] White, D.J., Jaselskis, E., Schaefer, V., and Cackler, E. (2005). "Real-time compaction monitoring in cohesive soils from machine response." *Transportation Research Record,* No. 1936, National Academy Press, 173-180.

[7] Commuri, S., and Mai, A. (2009). "Field validation of the intelligent asphalt compaction analyzer." *Proc. 17th Mediterranean Conf. on Control and Automation,* June 24-26, Thessaloniki, Greece, 651-656.

[8] White, D.J., Thompson, M., and Vennapusa, P. (2007a). *Field validation of intelligent compaction monitoring technology for unbound materials.* Final Report MN/RC-2007-10, Minnesota Department of Transportation, St. Paul, Minnesota.

[9] White, D.J., Vennapusa, P., Zhang, J., Gieselman, H., and Morris, M. (2009) *Implementation of intelligent compaction performance based specifications in Minnesota,* Final Report MN/RC-2009-14, Minnesota Department of Transportation, St. Paul, Minnesota.

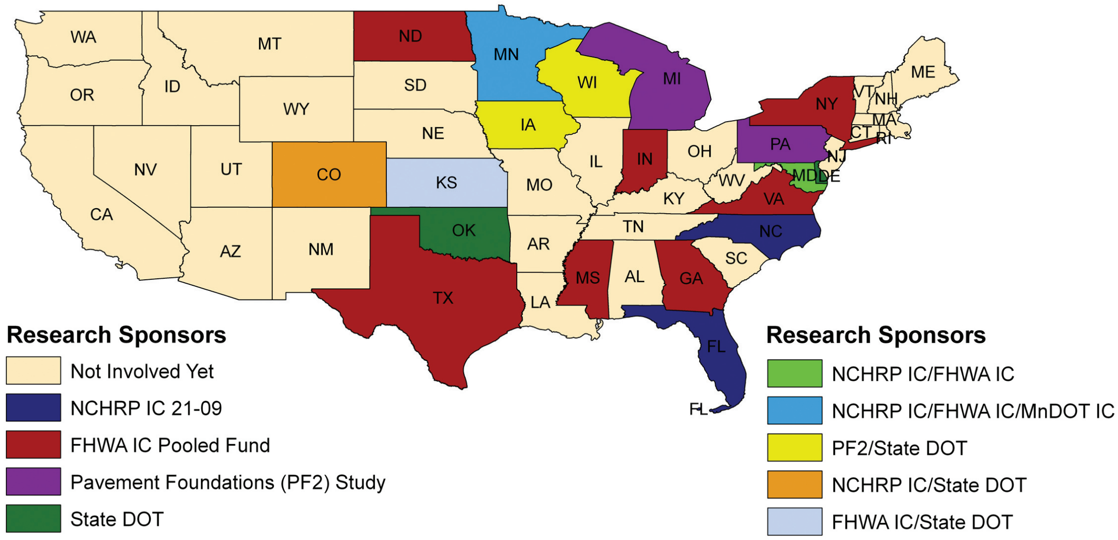

Figure 1. States that participated in intelligent compaction research/demonstration projects

As an outcome of the 2008 workshop, the need for correlations between IC/CCC measurement values and traditionally used point measurements (e.g., relative compaction, modulus, strength, etc.) was identified as the top research need.[1] For earth materials, using relative compaction (i.e., density) and moisture content for quality assurance (QA) and quality control (QC) are common. Similarly, a density measurement (to determine air void contents) is also a common QA/QC measurement for HMA. IC/CCC measurements are generally better correlated with mechanistic stiffness/strength measurements than with relative compaction. Correlating IC/CCC measurements to mechanistic measurements has the advantage of potentially verifying pavement design parameters. Use of in situ QA/QC methods that provide mechanistic measurements (e.g., light weight deflectometer [LWD], falling weight deflectometer [FWD], dynamic cone penetrometer [DCP]) are increasingly being considered by state and federal agencies.[8, 9, 10] More details on mechanistic QA/QC testing can be found elsewhere.[1,8,9,10]

Overview of Automated Machine Guidance

A research project was recently initiated by the National Cooperative Highway Research Program (NCHRP 10-77)[11] to help accelerate the implementation of AMG in the transportation industry. Application of AMG technology to transportation construction projects eliminates guesswork, reduces the need for skilled labor, and improves safety at construction sites. AMG has the potential to improve the efficiency of contractors and provide significant time and cost savings.[12] Some key obstacles that are hindering accelerated implementation of AMG technologies include (a) lack of a standardized process for

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[10] Puppala, A.J. (2008). *Estimating stiffness of subgrade and unbound materials for pavement design*, NCHRP Synthesis 382, Transportation Research Board, Washington, D.C.

[11] NCHRP 10-77 - *Use of Automated Machine Guidance (AMG) within the Transportation Industry* http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2504> Date Accessed 11/15/2009.

[12] *Automated Machine Guidance – Brochure,* AASHTO Technology Implementation Guide (TIG). <http://tig.transportation.org/sites/aashtotig/docs/tigamgbrochurefinal.pdf> Date Accessed 11/15/2009.

Table 1. Intelligent compaction research/demonstration projects to date in the US

Year	Project Title	Sponsors	Performing Organization
2003	Exploring Vibration-Based Intelligent Soil Compaction	Oklahoma DOT, FHWA	University of Oklahoma
2003	Intelligent Compaction: Overview and Research Needs	FHWA	Texas A&M University
2004	Field Evaluation of Compaction Monitoring Technology: Phase 1	Iowa DOT, FHWA, Caterpillar, Inc.	Iowa State University
2005	Continuous Compaction Control MnROAD Demonstration	Mn/DOT	CNA Consulting Engineers
2006	New Technologies and Approaches to Controlling the Quality of Flexible Pavement Construction	TxDOT, FHWA	Texas A&M University
2006	Field Evaluation of Compaction Monitoring Technology, Phase 2	Iowa DOT, FHWA	Iowa State University
2006	Advanced Compaction Quality Control	Indiana DOT, FHWA	Purdue University
2006	Intelligent Compaction and In Situ Testing at Mn/DOT TH53	Mn/DOT	CAN Consulting Engineers
2007	Field Study of Compaction Monitoring Systems: Self-Propelled Non-Vibratory 825G and Vibratory Smooth Drum CS-533E	Caterpillar, Inc.	Iowa State University
2007	CAREER: Geo Works: Multidisciplinary Design Studio Fostering Innovation and Invention in Geo-Construction through Research, Development, and Education	National Science Foundation	Colorado School of Mines
2007†	Field Validation of Intelligent Compaction Monitoring Technology for Unbound Materials	Mn/DOT, FHWA	Iowa State University
2007	Preliminary Field Investigation of Intelligent Compaction of Hot-Mix Asphalt	Virginia Department of Transportation	Virginia Transportation Research Council
2008	Intelligent Compaction Implementation: Research Assessment	Mn/DOT, FHWA	University of Minnesota
2008	Field Evaluation of CS-563 and CS-683 Vibratory Smooth Drum Rollers	Caterpillar, Inc.	Iowa State University
2008	Demonstration of Intelligent Compaction Control for Embankment Construction in Kansas	Kansas DOT, FHWA	Kansas State University
2009†	Implementation of Intelligent Compaction Performance-Based Specifications in Minnesota	Mn/DOT	Iowa State University
2009	Intelligent Soil Compaction Systems	NCHRP	Colorado School of Mines, Iowa State University
Active	Evaluation of Intelligent Compaction Technology for Densification of Roadway Subgrade and Structural Layers	WisDOT	Applied Research and Associates, Inc.
Active	Development of Soil Stiffness Measuring Device for Pad Foot Roller Compactor	Colorado DOT, Mn/DOT, FHWA	Colorado School of Mines
Active	Intelligent Asphalt Compaction Analyzer	Oklahoma DOT, FHWA	University of Oklahoma
Active	Investigation of Intelligent Compaction Technology	DelDOT	University of Delaware
Active	Intelligent Compaction for Evaluation of Geogrid-Reinforced Base Material	Tensar International Corp.	Iowa State University
Active	Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials	FHWA Pooled Fund Study	The Transtec Group, Inc., Iowa State University
Active†	Iowa DOT Intelligent Compaction Research and Implementation	Iowa DOT	Iowa State University

†Projects with IC specification implementation on pilot projects

development and transfer of 3D electronic files, (b) a general lack of knowledge in technical aspects, (c) legal barriers, and (d) lack of documented case studies demonstrating the benefits of the AMG technology.

A few state DOTs (e.g., Colorado, California, Iowa, Minnesota, New York, and Wisconsin) have developed specifications to implement AMG on transportation construction projects. As part of the workshop breakout sessions, the groups were asked to develop a framework to move AMG technology forward into the mainstream of highway construction. As an example, a copy of the Iowa DOT developmental specifications (see Appendix C) was provided for the workshop participants. Discussion and results from the breakout sessions are provided later in this report.

Summary of the 2008 Workshop

One of the key outcomes from the 2008 workshop was that a follow-up workshop was highly encouraged to continue identifying opportunities to advance applications of new technologies. Approximately 100 participants, with representatives from several state DOTs, FHWA, industry/manufacturers, contractors, and universities, attended the 2008 workshop. The workshop involved several technical presentations, nine breakout sessions covering three topic areas ("IC for soils and Aggregate," "IC for HMA," and "Implementation Strategies"), a panel discussion, and a group exercise to identify implementation strategies. The workshop proceedings summarize the workshop events and outcomes (see Figure 2).[1] Some of the significant outcomes of the 2008 workshop included identifying (a) the top 10 IC technology research needs, (b) *where we are and where we are going,* and (c) strategies for moving forward. The workshop provided an excellent platform for collaboratively exchanging ideas and taking initiative to accelerate implementation of IC technologies. The proceedings provided a *road map* for implementation that identified key research and training focal areas. The road map was evaluated as part of the 2009 workshop and is discussed later.

Guidelines for IC Developmental Specifications

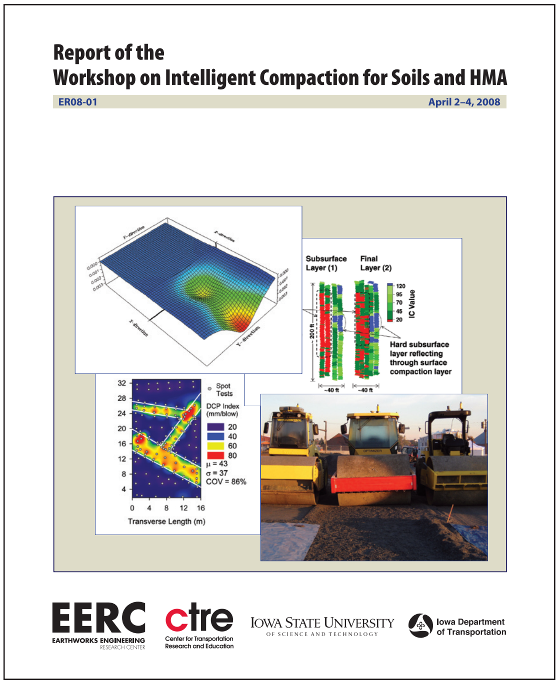
Participants were given a handout with key attributes of IC specifications, a summary comparing current IC specifications,[13, 14] a list of IC specifications–related literature, and five possible specification options (including options for performance specifications). These documents are discussed later in this report. A key outcome of the discussions was a revised key attributes list for IC specifications.

Draft Key Attributes of IC Specifications

The following are considered key attributes of IC specifications. Although current IC specifications (see Table 1) have common language for many of these attributes, the largest differences exist with attribute item number 10.

[13] ISSMGE. (2005). Roller-Integrated continuous compaction control (CCC): Technical Contractual Provisions, Recommendations, TC3: Geotechnics for Pavements in Transportation Infrastructure. International Society for Soil Mechanics and Geotechnical Engineering.

[14] Mn/DOT. (2007). Excavation and embankment – (QC/QA) IC quality compaction (2105) pilot specification. Minnesota Department of Transportation, St. Paul, Mn.



Common Themes from Panel Discussion Session

1. High level of interest from the state DOTs in further studying opportunities to implement IC.
2. Implementation strategies need to build on existing information and past research.
3. Specifications for IC and in situ testing should not restrict manufacturer/equipment developer innovations.
4. Contractor and state DOT field personnel and engineers need educational materials for IC and in situ QC/QA testing.

Common Themes from Group Implementation Strategy Session

1. Develop IC training and certification program.
2. Demonstrate benefits of IC through demonstration projects.
3. Promote partnership as key strategy to implementation.

Where we are:

- Lack widely accepted IC specifications in U.S.
- Need education/training materials
- Innovative IC and in situ testing equipment
- IC technologies provide documented benefits (smooth drum - granular)
- Great potential and some limited successes for cohesive and HMA
- Poor database development for IC projects and case histories
- Initiated human IC network
- Increasing acceptance/GPS infrastructure for stakeless grading/machine guidance
- “Don’t know what we don’t know”

Where we are going:

- Standardized and credible IC specifications inclusive of various IC measurement systems
- Widespread implementation of IC technologies
- High quality database of correlations
- Several documented successes for cohesive/stabilized/granular/HMA
- Better understanding of roadway performance - what are key parameters?
- Innovative new sensor systems and intelligent solutions
- Integrated and compatible 3D electronic plans with improved processes, efficiency and performance
- Real-time wireless data sharing
- Enhanced archival and visualization software
- Improved analytical models of machine-ground interactions

Top 10 IC Technology Research Needs

1. Need correlation studies (cohesive, stabilized, granular, HMA, etc.) (136)
2. Education/training materials and programs (112)
3. Moisture content (influence + measurement) (61)
4. Integrated design + real-time data transfer (57)
5. Case histories + demos + benefit + successes (48)
6. Engineering parameter to measure (density, modulus, stiffness, core mat temperature)? (47)
7. Addressing non-uniformity (34)
8. Establishing QC/QA framework - statistically significant (28)
9. Measurement influence depth? (19)
10. Promoting good geotechnical practices (13)

Strategies for Moving Forward

- Participate in partnerships for IC research and information exchange regionally and nationally
- Be an advocate for IC implementation
- Contribute to problem statement development for NCHRP, TRB, FHWA, AASHTO, ASCE Committees
- Participate in IC conferences/studies and the annual EERC Workshop
- Participate on EERC Scientific and Policy Advisory Council (35 members) – IC and other issues
- Stay connected: Subscribe to EERC Technical Bulletins, Tech Transfer Summaries, Technical Reports, Educational Videos, etc. (www.intelligentcompaction.com).
- Develop a comprehensive and strategic IC road map for research and educational/technology transfer

Figure 2. Report of the 2008 workshop, photos, and some key outcomes

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 QC and QA tests
9. Operator training
10. Acceptance procedures/corrective actions based on achievement of minimum MV target values (MV-TVs) and associated variability.

IC Specifications and Related Literature

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IC Specification Options

Table 2 summarizes IC specifications.

Table 2. Summary comparing 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	—
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.

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, a 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 implementating IC in 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 used to select 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. The numbers of tests and test locations are selected based on judgment. 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 analyses, including moisture content as a variable, may be needed. If underlying layer support conditions are heterogeneous, relationships are likely improved by performing multiple regression analyses with IC-MV or using 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 it 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 achieves 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.

Figure 3 summarizes and provides a framwork for four of the five different IC earthwork specification options.

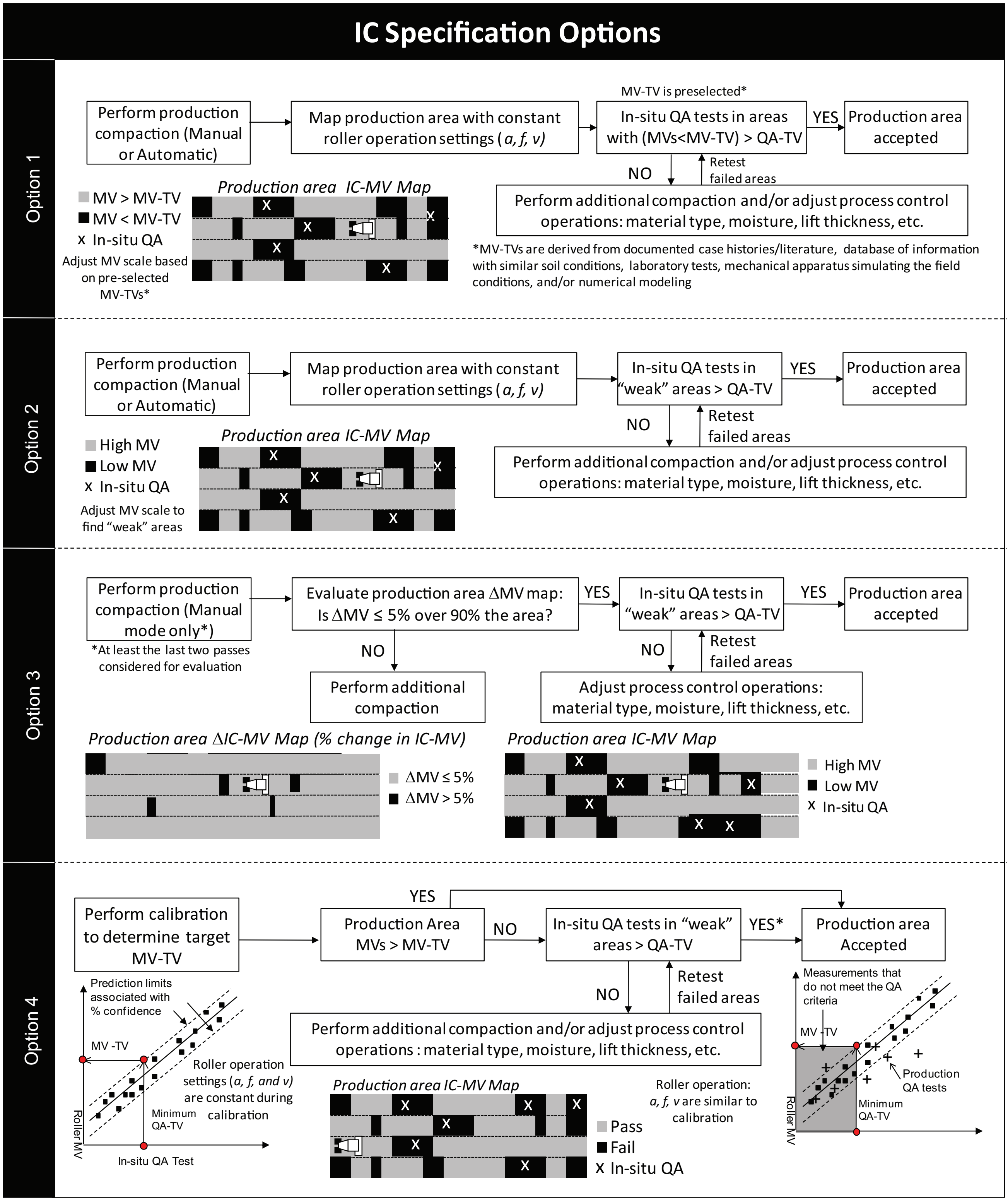


Figure 3. Framework for different IC earthwork specification options

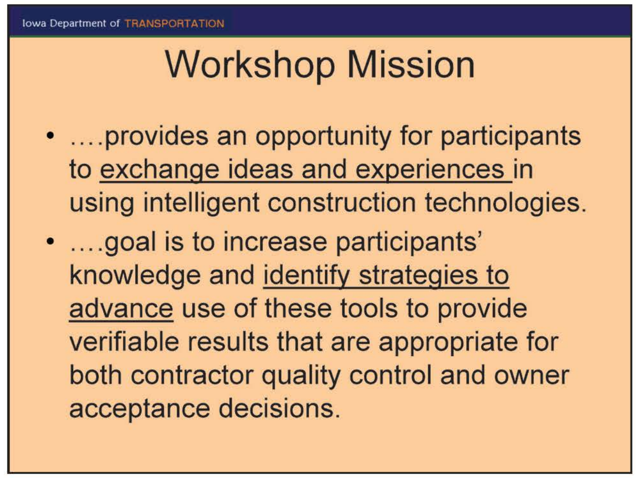
Presentations

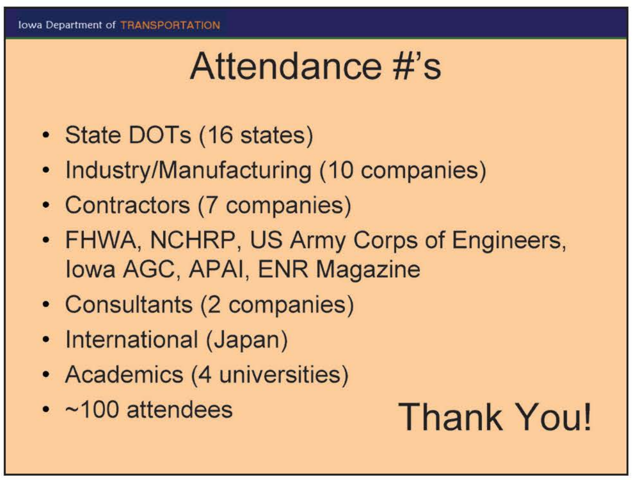
The following is a list of the presentations delivered at the workshop. The slides follow.

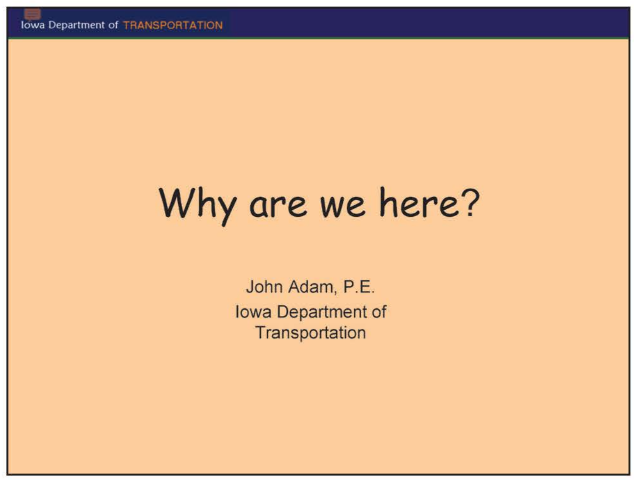
1. Welcome and Workshop Mission—Sandra Larson
2. 2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes —David White
3. Joint Rapid Airfield Construction (JRAC): U.S. Military's New Approach to Contingency Airfield Construction—Gary Anderton
4. IC Case Histories for Soil, Aggregate, and HMA—David White, Pavana Vennapusa, Rachel Goldsmith, and Luke Johanson
5. Mn/DOT's Experience with LWD and IC Implementation—Rebecca Embacher and Tim Andersen
6. Iowa Real-Time Network (Iowa RTN)—Mike Jackson
7. GPS Technology in Planning, Design, and Construction Delivery—Jeff Hannon; GPS Automatic Grade Control Systems, Engineering Distance Education—Charles Jahren; NCHRP 10-77—David White
8. Participating State DOT Briefings—David Jared and Brett Dening
9. Industry/Equipment Manufacturer Overviews
   - Intelligent Technologies Creating Intelligent Surfaces—Corey Johnson, Bentley
   - Overview of BOMAG IC Technology—Dave Dennison, BOMAG
   - Connected Worksite Solutions—Terry Rasmussen, Caterpillar
   - Dynapac Compaction Analyzer and Optimizer—Dynapac
   - Intelligent Compaction for Soils and Asphalt—Stan Rakowski, Sakai
   - Project Planning Using: GIS, GPS and RFID—Kelly Miller, Trimble
     Trimble, Construction Technology and Compaction Control Systems—Jeroen Snoeck, Trimble
10. Facilitators' Report / Discussion—Tom Cackler, Ed Engle, Heath Gieselman, John Hannon, Charles Jahren, Pavana Vennapusa, David White, Paul Wiegand, Caleb Douglas

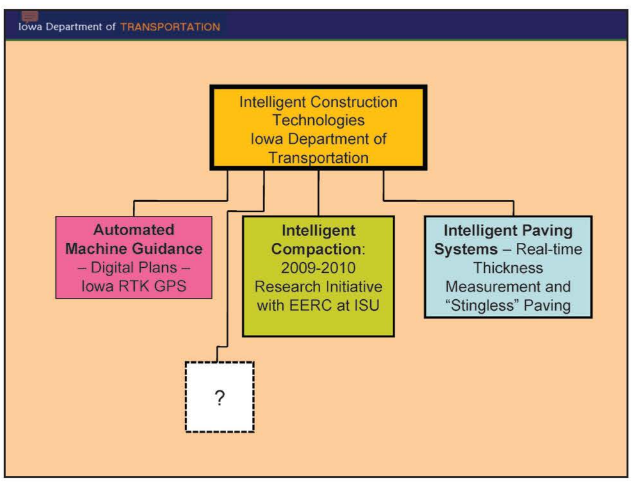
2009 Intelligent Construction Workshop for Earthworks
Welcome and Workshop Mission

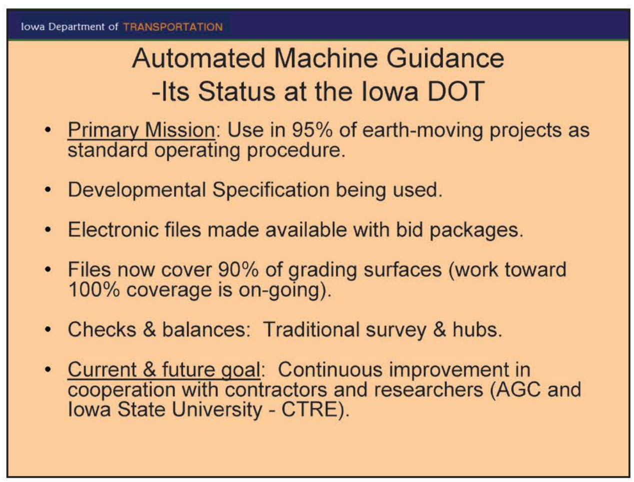
Sandra Larson











2009 Intelligent Construction Workshop for Earthworks
Welcome and Workshop Mission

Sandra Larson

Iowa Department of TRANSPORTATION

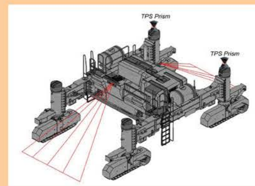
Intelligent Compaction Initiative

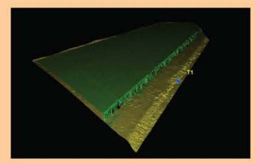
- Goal: to successfully implement intelligent compaction technologies through research and training that leads to improved road building quality, efficiency, and cost.
- Primary Tasks
  - Detailed demonstration projects (3 in 2009) for soil and HMA
  - Develop framework for IC database
  - Create pilot Developmental Specification and let project(s) (2010)
  - Create training program for Iowa DOT and contractor
- Collaborative effort with industry and EERC

Iowa Department of TRANSPORTATION

Intelligent Paving Systems

- "Using Scanning Lasers for Real-Time Pavement Thickness Measurement," IHRB Project TR-538
- "Stringless Portland Cement Concrete Paving," Iowa DOT Project TR-490





2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

David White

IOWA STATE UNIVERSITY
Civil, Construction & Environmental Engineering

2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

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

April 14, 2009

ctre | Iowa State University | EERC

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

Hard Work, Fun, New Partnership…

Workshop Overview

- 2.5 day event in Des Moines, IA in April 2008
- ~100 participants (State DOTs, FHWA, Contractors, Equipment Manufacturers, Academics)
- $$$ provided for State DOTs
- Technical Session, Breakout Working Sessions, Panel Discussion, Group Exercise
- Next Meeting Planned for April 14-16, 2009

http://www.ctre.iastate.edu/reports/intelligent-compaction-wkshp.pdf

Workshop Objectives and Vision

- Provide a collaborative exchange of ideas for developing research and educational initiatives that accelerate implementation of intelligent compaction technologies
- Create a roadmap for implementation that identifies several key research and training focal areas
- How did we do it?

Day 1 - Technical Presentations

1. Intelligent Compaction for Soils and Aggregate – Dr. David J. White
2. Intelligent Compaction (IC) for Hot Mix Asphalt (HMA) – Lee Gallivan
3. Automated Technologies in Construction – Dan Streett
4. Earthworks Engineering Research Center – Dr. David J. White
5. Intelligent Compaction at MnDOT – Glenn Engstrom, Craig Collison, and Art Bolland
6. European Experience with ICS – Francois Chaignon
7. Intelligent Compaction for Soil and Asphalt – Dean Potts
8. Asphalt Manager Intelligent Compaction – Chris Connolly
9. Intelligent Compaction for Soils & HMA – Stan Rakowski
10. Evaluation of Highway Subgrade Strength with Acceleration Wave of the Vibration Roller – Stan Rakowski
11. Intelligent Compaction …GPS-based Compaction Control – Kirby Carpenter
12. Intelligent Compaction – Khalil Maalouf
13. Intelligent Compaction: Where we are at and where we need to be – Brett Stanton
14. Facilitator Report – Discussion – Tom Cackler, Ed Engle, Heath Gieselman, Lisa Rold, Douglas Townes, David White

Technology – What is IC?

Bomag: E_{VIB}

Case/Ammann: k_s

Caterpillar: CMV, RMV, MDP

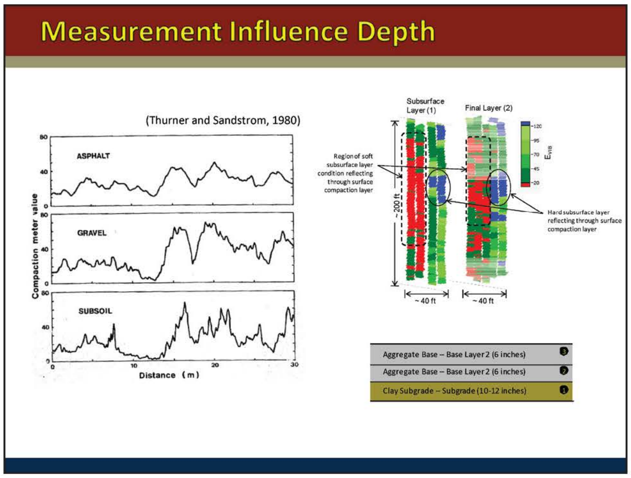
Dynapac: CMV, Bouncing Value

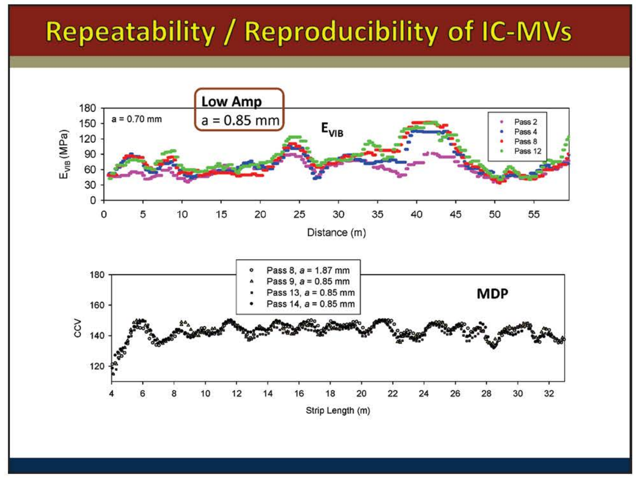
Sakai: CCV

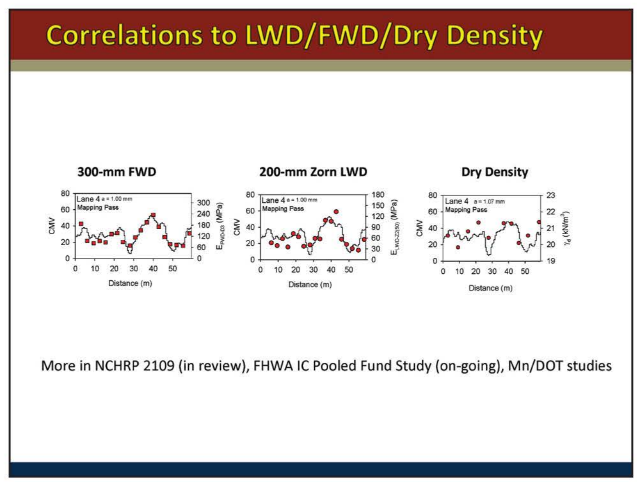
Volvo: CMV

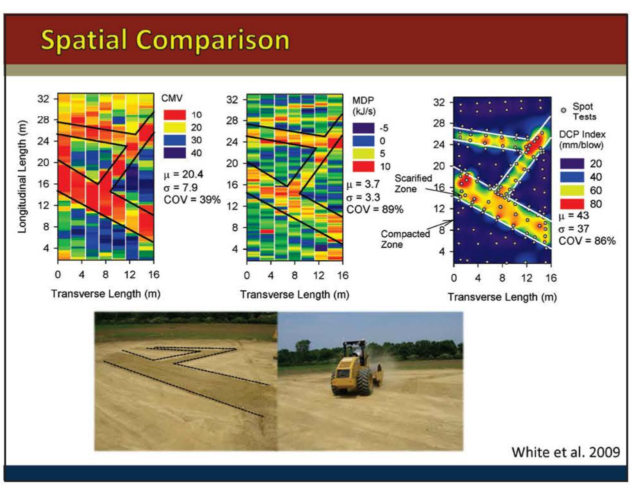
2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

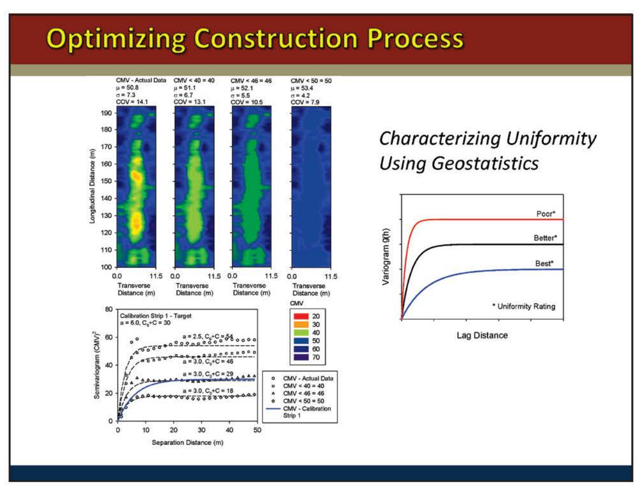
David White











2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

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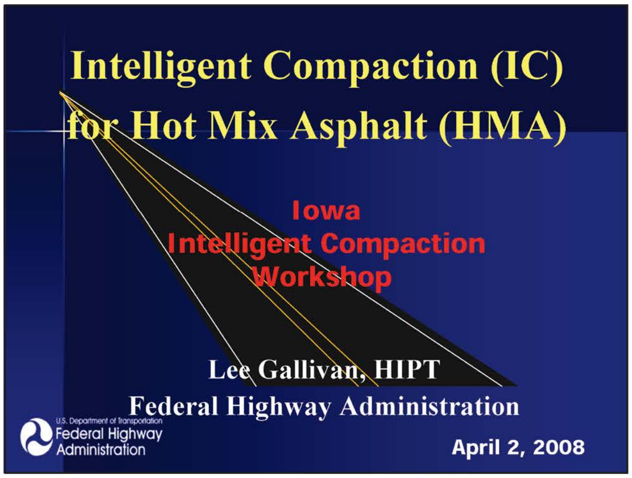
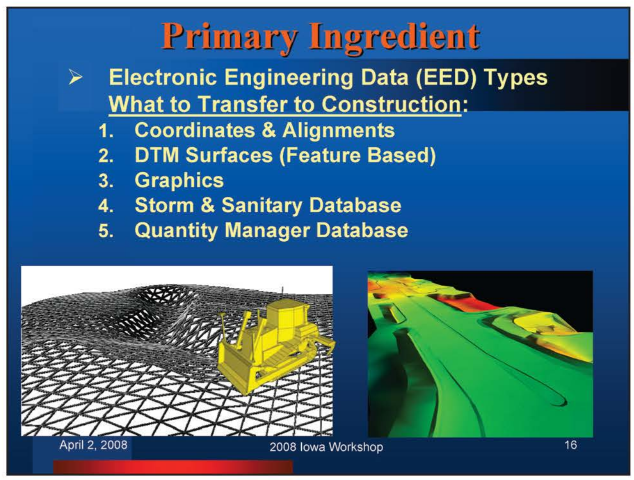
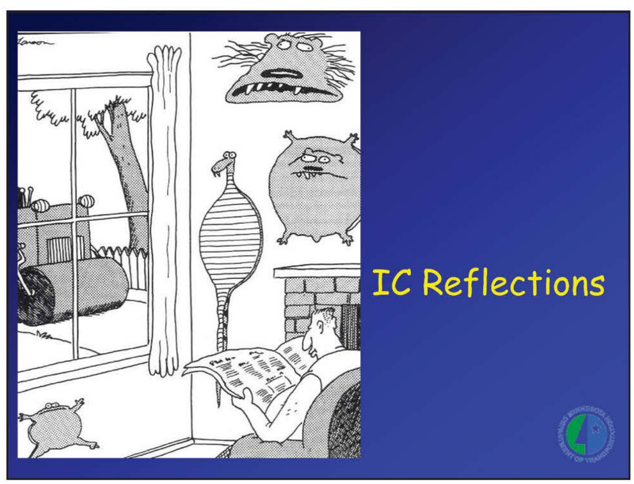




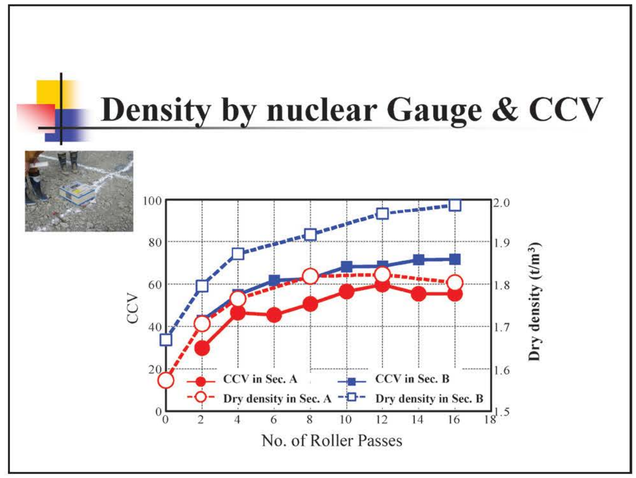


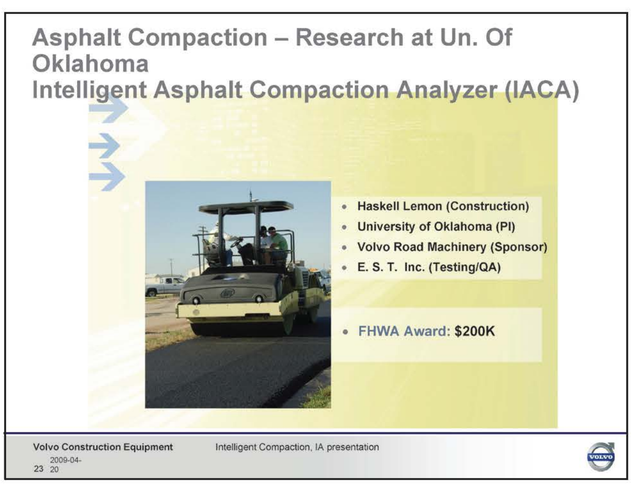
2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

David White

Evaluation of the highway subgrade strength with the acceleration wave of the vibration roller

Japan Highway Public Corp., Y. Kitamura & K. Fujioka
Sakai Heavy Industries, Ltd., K. Uchiyama
Fudo Construction Co., T. Nishio
Hazama Co., S. Nakajima





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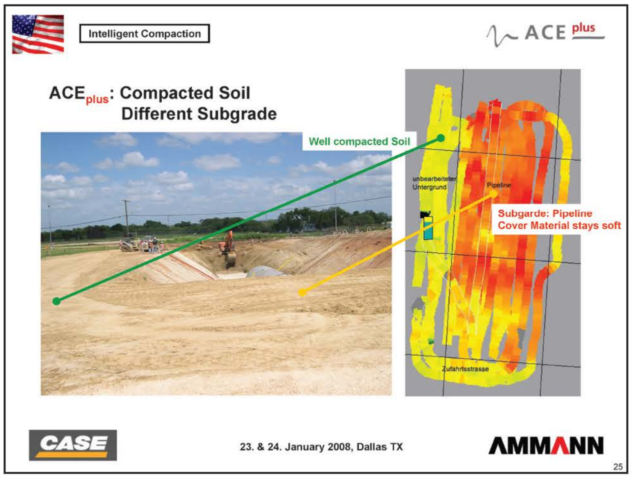
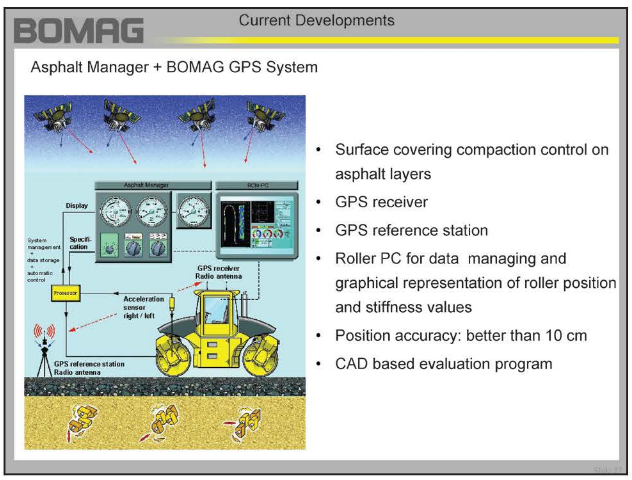
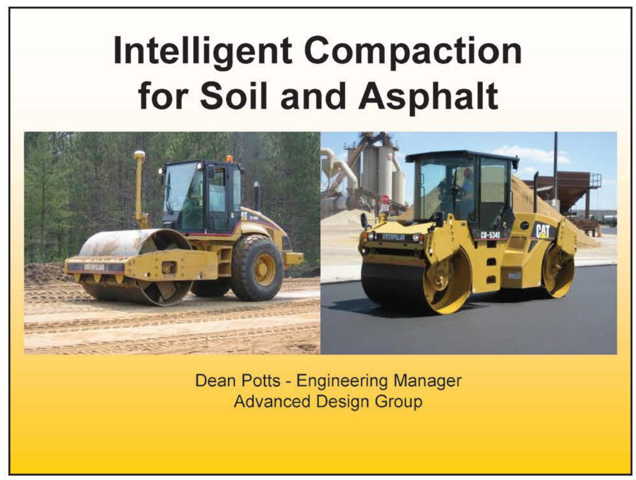
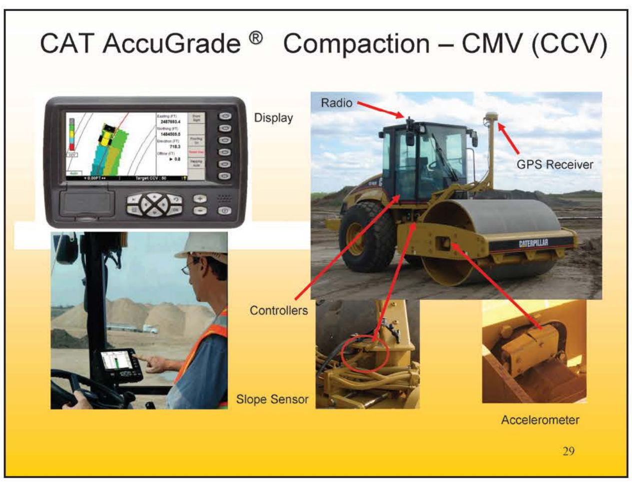
David White









2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

David White

INTRODUCTION

CONTRACTOR'S DEFINITION:

Intelligent compaction is a compaction system that allows increasing productivity while decreasing risk.

REGULATORY AGENCY'S DEFINITION:

Intelligent compaction is another means of measuring and recording the quality of compaction during the construction process.

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Day 2 - Working Sessions

- IC for Soils and Aggregate
- IC for HMA
- Implementation Strategies

Knowledge Gaps | Equipment Advancements | Education and T^2 | Specifications and Standards

Outcome: Develop a framework to move intelligent compaction/machine control forward into the mainstream of highway construction.

Identify Constraints ☑ → Strategies to Overcome ☑ → Action Plan/Tasks → Successful Outcome

Summary Points

Table 2. Summary of main IC technology research needs

Top 10 IC Technology Research Needs

1. Need correlation studies (cohesive, stabilized, granular, HMA, etc.) (136)
2. Education/training materials and programs (112)
3. Moisture content (influence + measurement) (61)
4. Integrated design + real-time data transfer (57)
5. Case histories + demos + benefit + successes (48)
6. Engineering parameter to measure (density, modulus, stiffness, core mat temperature)? (47)
7. Addressing non-uniformity (34)
8. Establishing QC/QA framework - statistically significant (28)
9. Measurement influence depth? (19)
10. Promoting good geotechnical practices (13)

Summary Points

Table 3. Summary of common themes from panel discussion

Common Themes from Panel Discussion Session

1. High level of interest from the state DOTs in further studying opportunities to implement IC.
2. Implementation strategies need to build on existing information and past research.
3. Specifications for IC and in situ testing should not restrict manufacturer/equipment developer innovations.
4. Contractor and state DOT field personnel and engineers need educational materials for IC and in situ QC/QA testing.

Table 4. Summary of common themes from the group implementation strategy session

Common Themes from Group Implementation Strategy Session

1. Develop IC training and certification program.
2. Demonstrate benefits of IC through demonstration projects.
3. Promote partnership as key strategy to implementation.

Summary Points

Table 5. Summary of key points

Where we are:	Where we are going:
• Lack widely accepted IC specifications in U.S. • Need education/training materials • Innovative IC and in situ testing equipment • IC technologies provide documented benefits (smooth drum - granular) • Great potential and some limited successes for cohesive and HMA • Poor database development for IC projects and case histories • Initiated human IC network • Increasing acceptance/GPS infrastructure for stakeless grading/machine guidance • "Don't know what we don't know"	• Standardized and credible IC specifications inclusive of various IC measurement systems • Widespread implementation of IC technologies • High quality database of correlations • Several documented successes for cohesive/stabilized/granular/HMA • Better understanding of roadway performance - what are key parameters? • Innovative new sensor systems and intelligent solutions • Integrated and compatible 3D electronic plans with improved processes, efficiency and performance • Real-time wireless data sharing • Enhanced archival and visualization software • Improved analytical models of machine-ground interactions

Summary Points

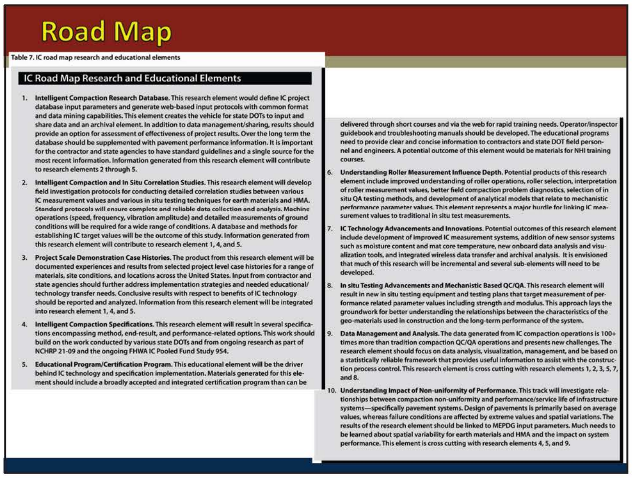
Table 6. Strategies for moving forward

Strategies for Moving Forward

- Participate in partnerships for IC research and information exchange regionally and nationally
- Be an advocate for IC implementation
- Contribute to problem statement development for NCHRP, TRB, FHWA, AASHTO, ASCE Committees
- Participate in IC conferences/studies and the annual EERC Workshop
- Participate on EERC Scientific and Policy Advisory Council (35 members) – IC and other issues
- Stay connected: Subscribe to EERC Technical Bulletins, Tech Transfer Summaries, Technical Reports, Educational Videos, etc. (www.intelligentcompaction.com).
- Develop a comprehensive and strategic IC road map for research and educational/technology transfer

2008 Intelligent Compaction Soils and HMA: Review of Workshop Outcomes

David White

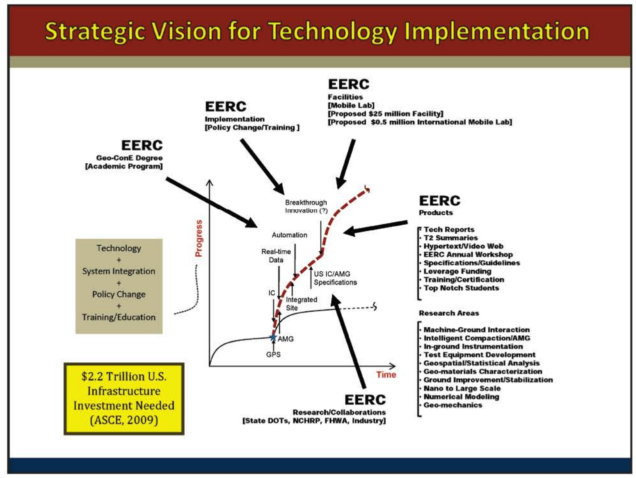


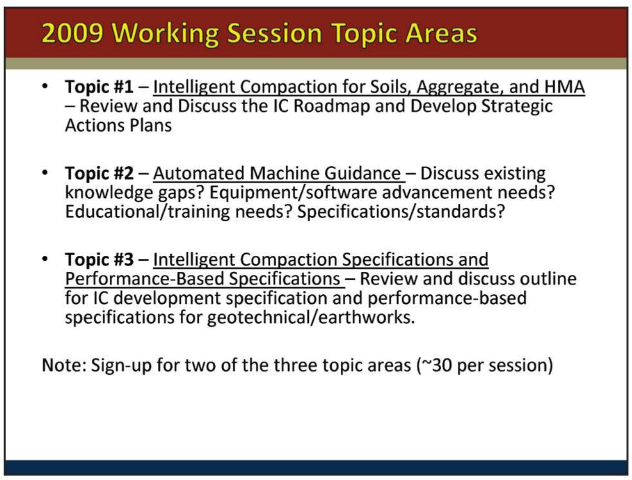
Road Map

Table 7. IC road map research and educational elements

IC Road Map Research and Educational Elements

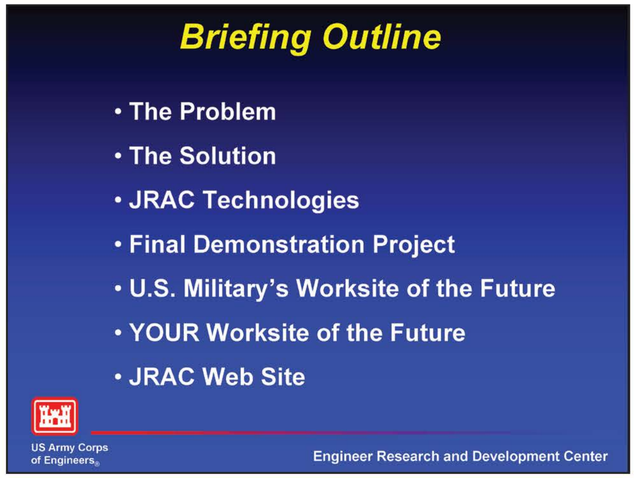
1. **Intelligent Compaction Research Database.** This research element would define IC project database input parameters and generate web-based input protocols with common format and data mining capabilities. This element creates the vehicle for state DOTs to input and share data and an archival element. 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 2 through 5.
2. **Intelligent Compaction and In Situ Correlation Studies.** This research element will develop field investigation protocols for conducting detailed correlation studies between various 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 element 1, 4, and 5.
3. **Project Scale Demonstration Case Histories.** 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, 4, and 5.
4. **Intelligent Compaction Specifications.** This research element will result in several specifications encompassing method, end-result, and performance-related options. This work should build on the work conducted by various state DOTs and from ongoing research as part of NCHRP 21-09 and the ongoing FHWA IC Pooled Fund Study 954.
5. **Educational Program/Certification Program.** 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. **Understanding Roller Measurement Influence Depth.** 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.
7. **IC Technology Advancements and Innovations.** 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.
8. **In situ Testing Advancements and Mechanistic Based QC/QA.** 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. **Data Management and Analysis.** The data generated from IC compaction operations is 100+ times more than tradition 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, 5, 7, and 8.
10. **Understanding Impact of Non-uniformity of Performance.** 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 4, 5, and 9.

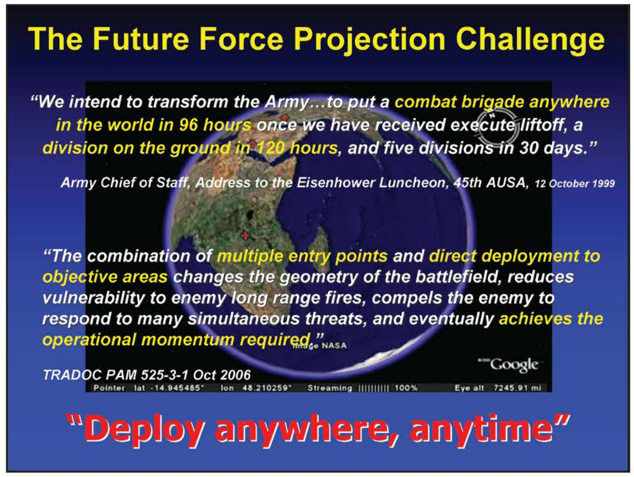


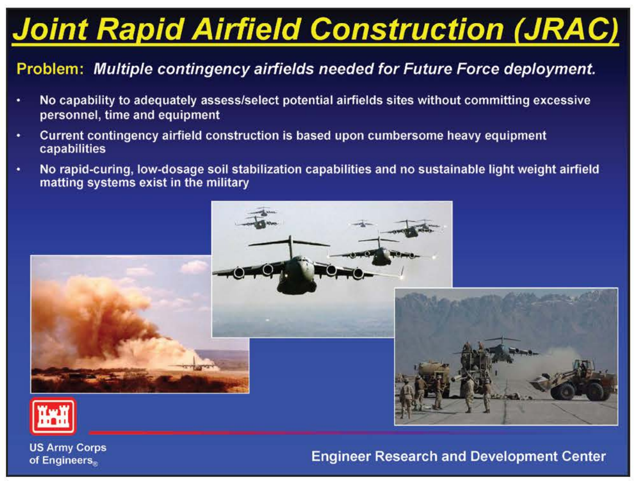


Joint Rapid Airfield Construction (JRAC): U.S. Military's New Approach to Contingency Airfield Construction

Gary Anderton







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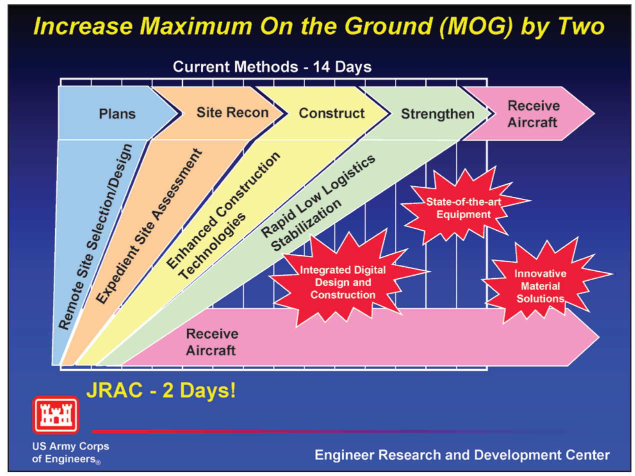

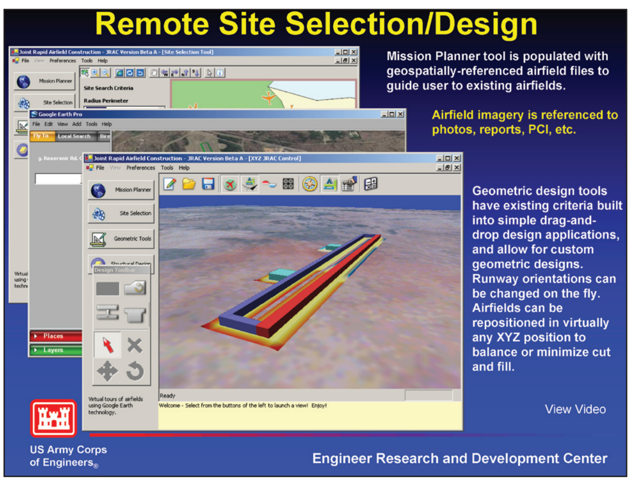

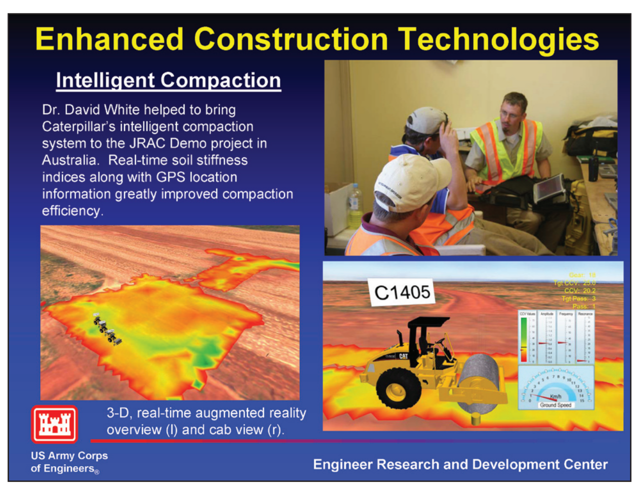

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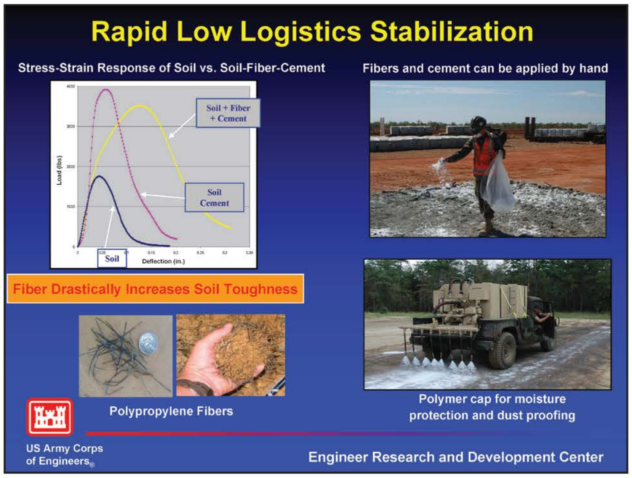

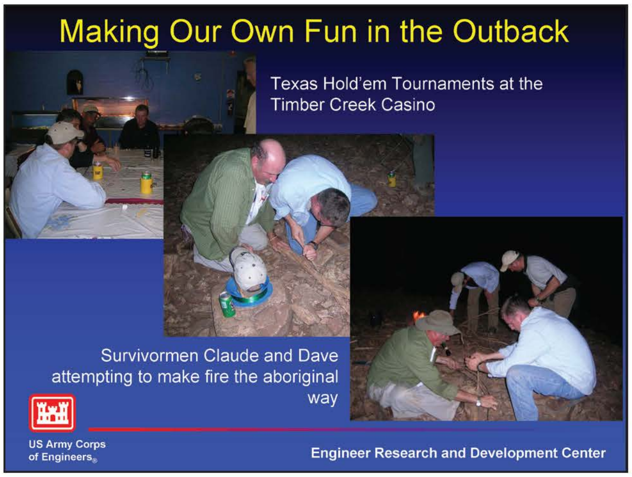

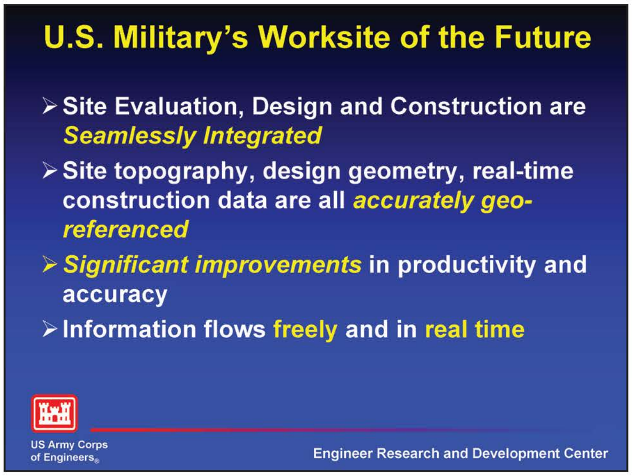

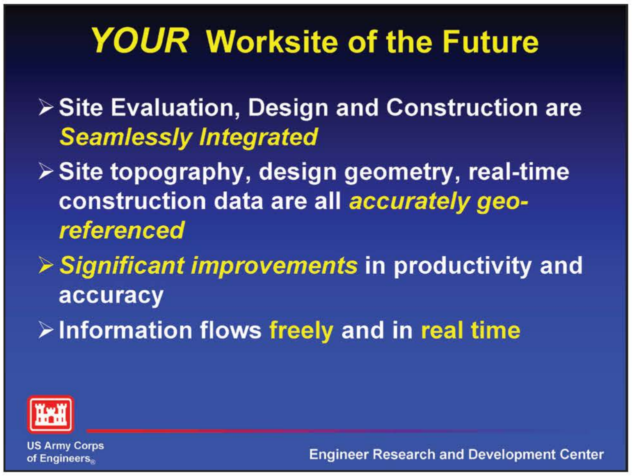

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IC Case Histories for Soil, Aggregate, and HMA

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IOWA STATE UNIVERSITY
Civil, Construction & Environmental Engineering

IC Case Histories for Soil, Aggregate, and HMA

2nd Annual Intelligent Construction for Earthworks Workshop
Sheraton Hotel, West Des Moines, Iowa
April 14, 2008

David J. White, Ph.D.
Pavana KR. Vennapusa, Ph.D.
Rachel Goldsmith
Luke Johanson

IOWA STATE UNIVERSITY EERC EARTHWORKS ENGINEERING RESEARCH CENTER

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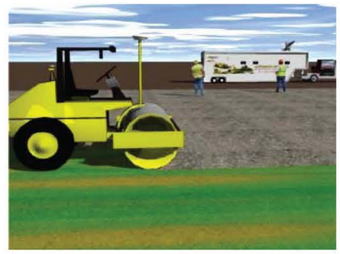
Premise



IC measurements are empirically related to in-situ point measurements (γ_d, w%, DCP, E_{LWD}, E_{FWD} etc.) and influenced by roller size, vibration amplitude, vibration frequency, velocity, soil type, and soil stratigraphy.

Caterpillar: CMV, RMV, MDP

Dynapac: CMV, Bouncing Value

Bomag: E_{VIB}

Sakai: CCV

Case/Ammann: k_s

Volvo: CMV

Technology

IC Measurement Values

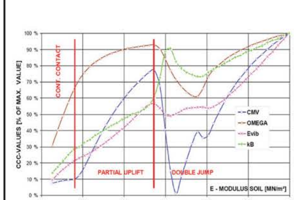
Manufacturer	Roller-Integrated Measurement Features	
	Compaction Measurement	Feedback Control
Ammann	$k_s = 4\pi^2 f^2 \left(m_d + \frac{m_e r_e \cos(\varphi)}{A} \right)$	Adjusts amplitude and frequency
Bomag	$z_d = \frac{(1-\upsilon^2)}{E_{vib}} \cdot \frac{F_s}{L} \cdot \frac{2}{\pi} \cdot \left(1.8864 + \ln \frac{L}{B} \right)$ where, $B = \sqrt{\frac{16}{\pi} \cdot \frac{R(1-\upsilon^2)}{E_{vib}} \cdot \frac{Fs}{L}}$	Adjusts amplitude direction on the drum
Caterpillar	$Geodynamik\ CMV = C\left(\frac{A_{2\Omega}}{A_\Omega}\right)$ $Geodynamik\ RMV = \frac{A_{0.5\Omega}}{A_\Omega}$ $MDP = P_g - WV\left(\sin\alpha + \frac{a}{g}\right) - (mV + b)$	Adjusts amplitude based on RMV
Dynapac	$Geodynamik\ CMV = C\left(\frac{A_{2\Omega}}{A_\Omega}\right)$ $Bouncing\ Value = \frac{A_{0.5\Omega}}{A_\Omega}$	Adjusts amplitude based on bouncing value
Sakai	$CCV = \left[\frac{A_{0.5\Omega} + A_{1.5\Omega} + A_{2\Omega} + A_{2.5\Omega} + A_{3\Omega}}{A_{0.5\Omega} + A_\Omega}\right] \times 100$	No

Influence of Drum Operating Mode

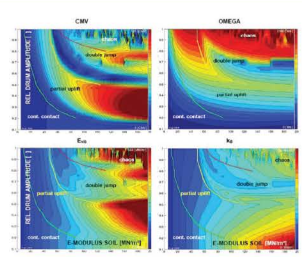
drum motion	Interaction drum-soil	operating condition	soil contact force	application of CCC	soil stiffness	roller speed	drum amplitude
periodic	continuous contact	CONT. CONTACT		yes	low	fast	small
periodic	periodic loss of contact	PARTIAL UPLIFT		yes	↓	↑	↓
periodic	periodic loss of contact	DOUBLE JUMP		yes	↓	↑	↓
periodic	periodic loss of contact	ROCKING MOTION	left / right	no	↓	↑	↓
chaotic	non-periodic loss of contact	CHAOTIC MOTION		no	high	slow	large

Summary of operating modes (from Adam and Kopf 2004)

Influence of Drum Operating Mode



Influence of drum operating condition on roller MVs relative to soil stiffness



Roller MV variation with soil modulus and drum vibration amplitude

(results of numerical simulations, from Adam and Kopf 2004)

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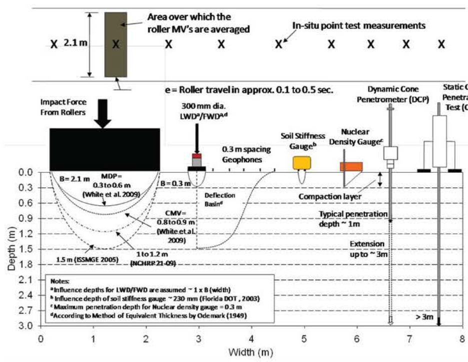
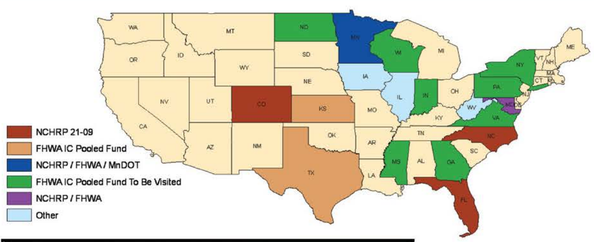
Measurement Influence Depth



In-Situ Testing Methods

IC Projects



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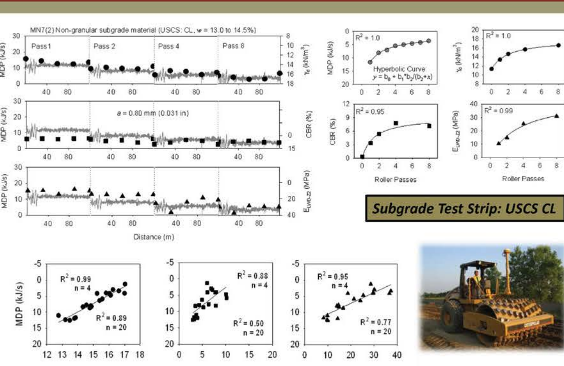
Case Histories

1. NCHRP Minnesota MnROAD
2. NCHRP Maryland I-70
3. NCHRP Colorado I-25
4. NCHRP North Carolina US311
5. NCHRP Florida I-10
6. FHWA Minnesota Rt. 4
7. Mn/DOT TH36
8. Mn/DOT TH60
9. FHWA Texas FM156
10. FHWA Kansas US69

MnROAD Research Facility
Albertville, Minnesota
NCHRP 21-09

MDP Vs. Point Measurements



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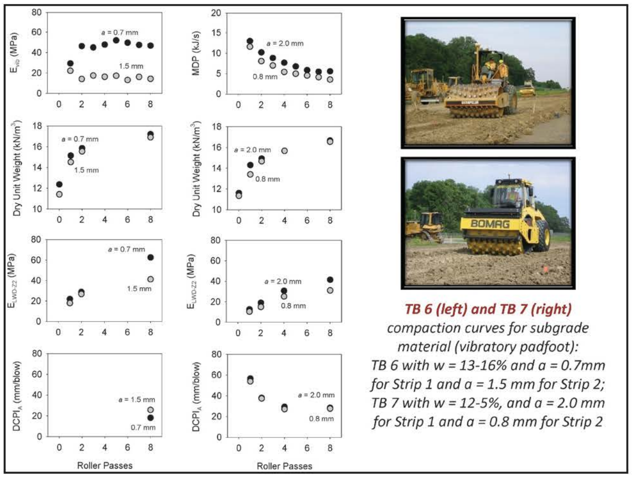

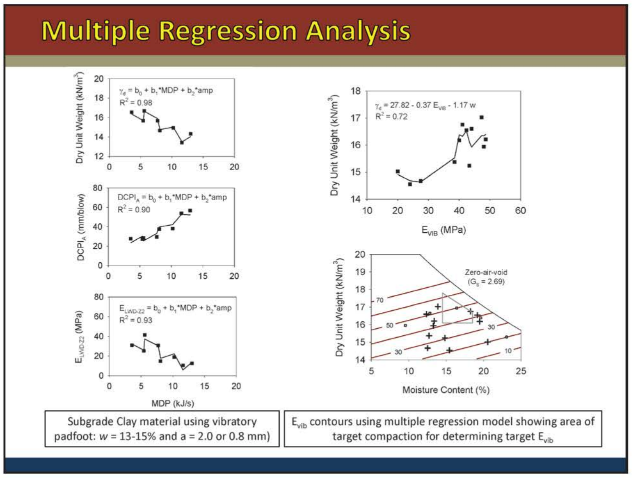

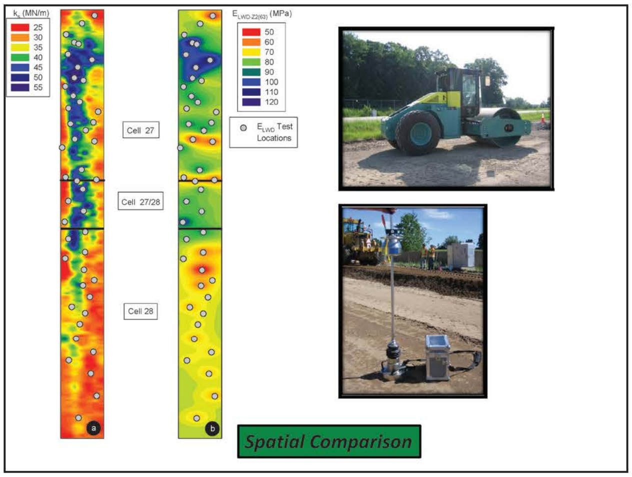

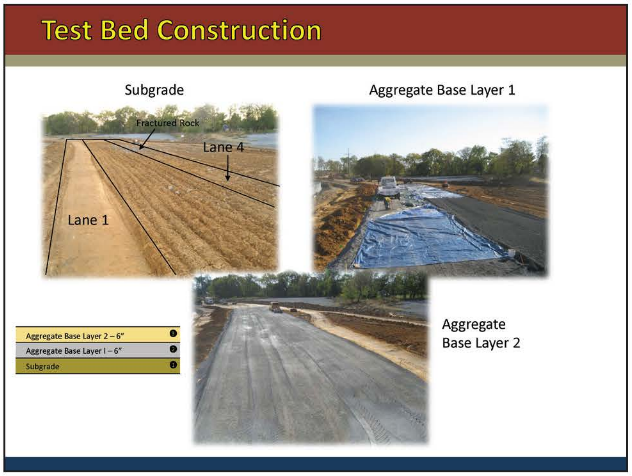

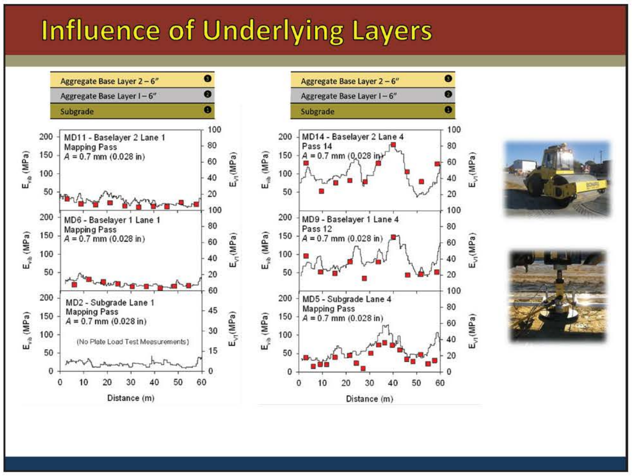

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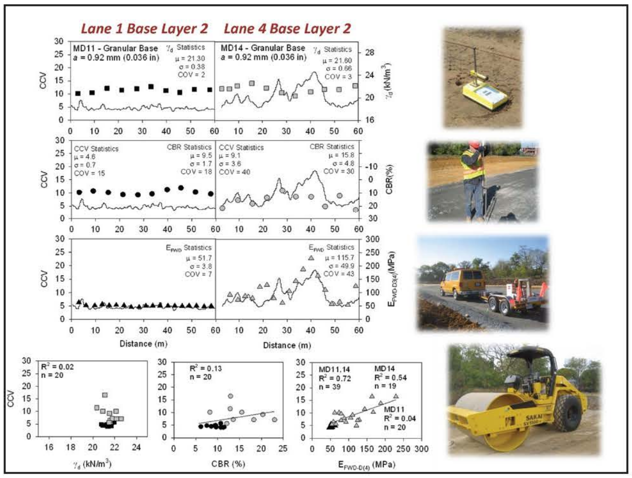
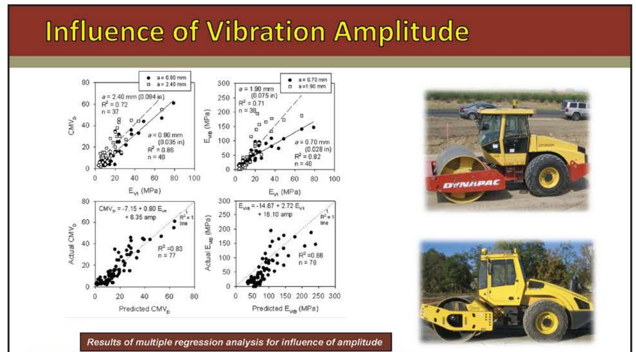
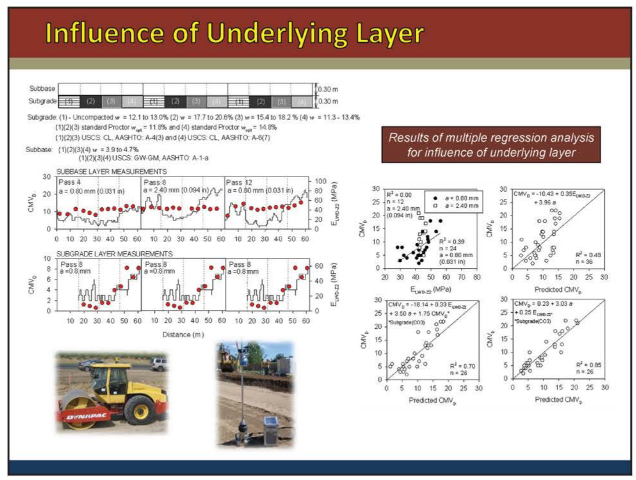
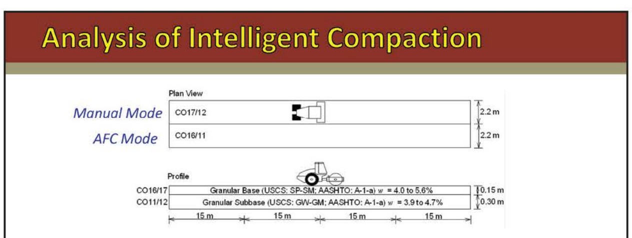




Results of multiple regression analysis for influence of amplitude

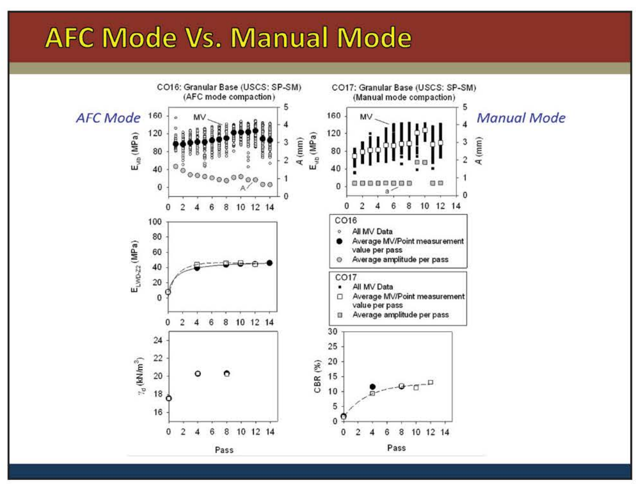
Model	Term	Estimate	Std Error	t Ratio	Prob>t (p value)	R^2
$CMV_D = b_0 + b_1 E_{V1} + b_3 a$	b_0	-7.15	1.78	-4.01	0.0001	0.83
	b_1	0.80	0.05	17.06	<0.0001	
	b_3	6.35	0.99	6.41	<0.0001	
$E_{vib} = b_0 + b_1 E_{V1} + b_3 a$	b_0	-14.67	9.28	-1.58	0.1183	0.66
	b_1	2.72	0.23	12.02	<0.001	
	b_3	16.10	5.77	2.79	0.0066	





Parameter	COV (%)					
	CO16		**CO11[a]**	CO17		**CO12[a]**
	Pass 8 (AFC)	Pass 14 (Manual)	**Pass 12 (Manual)**	Pass 8 (Manual)	Pass 12 (Manual)	**Pass 12 (Manual)**
E_{vib}	12	21	**12**	21	21	**18**
E_{LWD-Z2}	12	10	**14**	10	10	**15**
g_d	1	–	**2**	1	2	**2**
CBR	22	–	**21**	29	25	**21**

[a]underlying subbase layer



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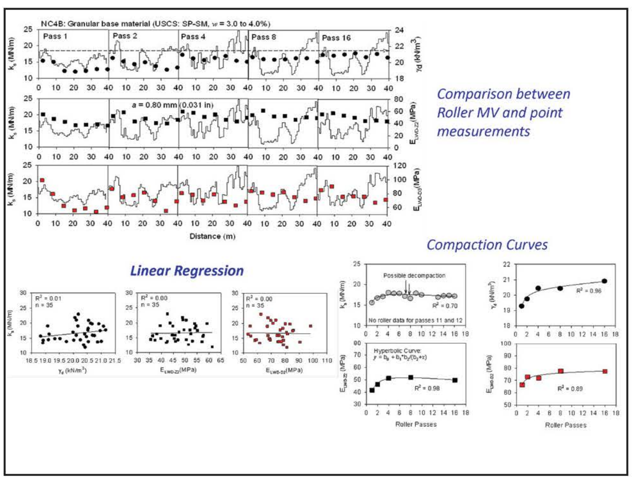

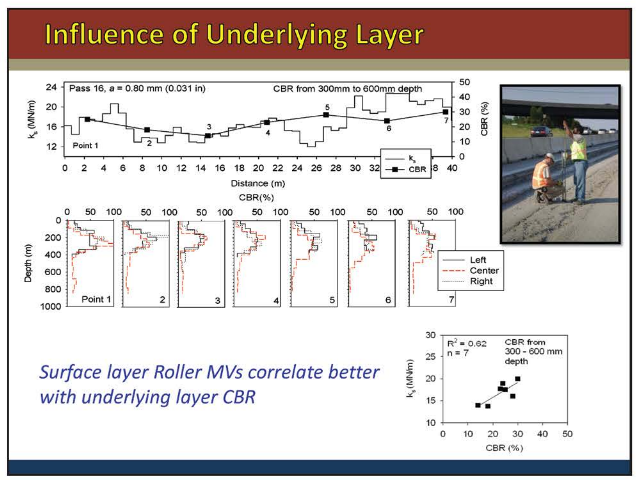

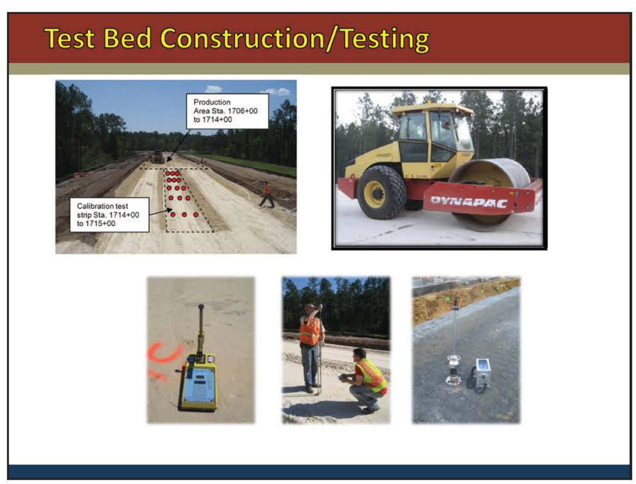

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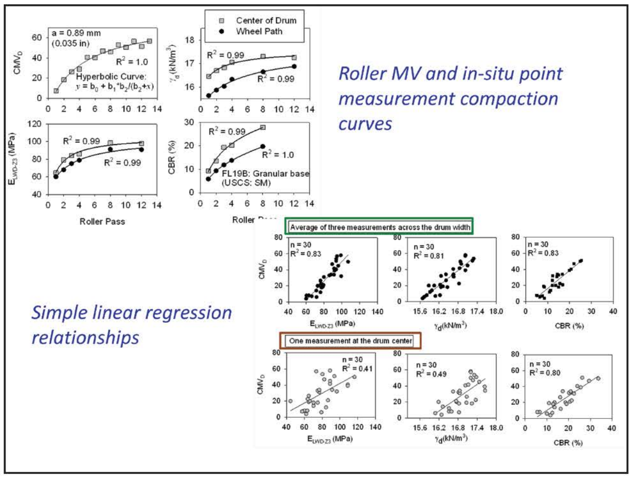
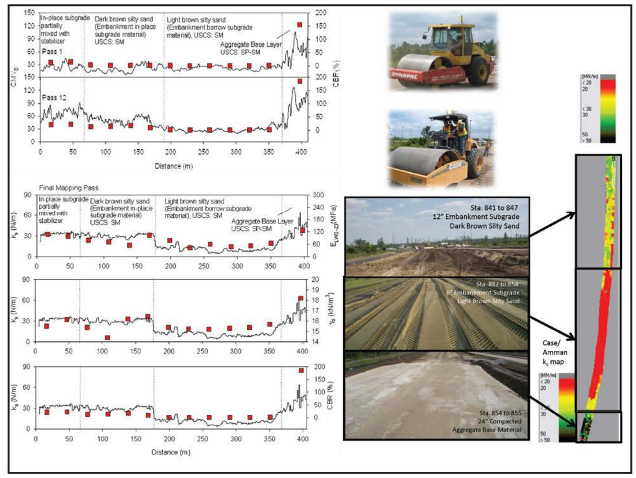
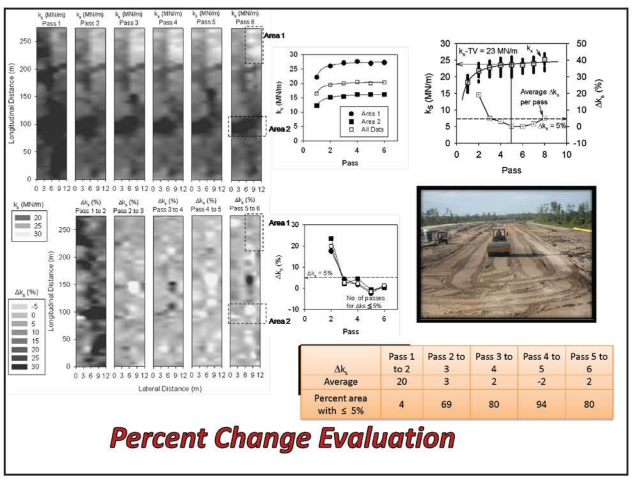
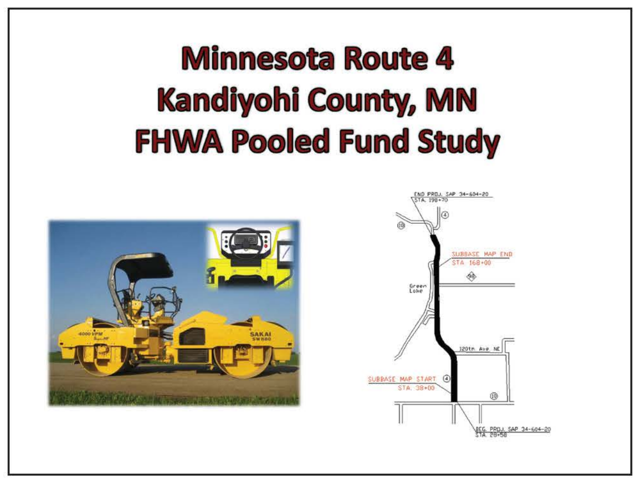
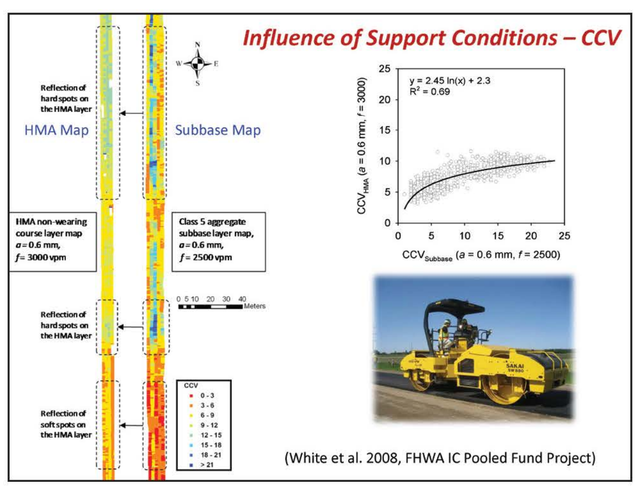






Δk_s	Pass 1 to 2	Pass 2 to 3	Pass 3 to 4	Pass 4 to 5	Pass 5 to 6
Average	20	3	2	-2	2
Percent area with ≤ 5%	4	69	80	94	80





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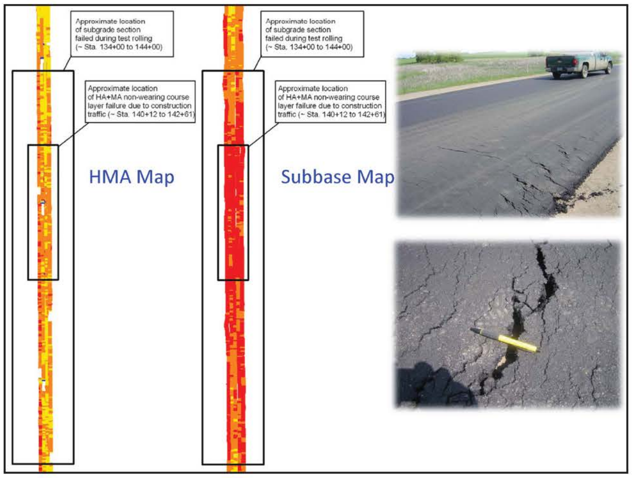

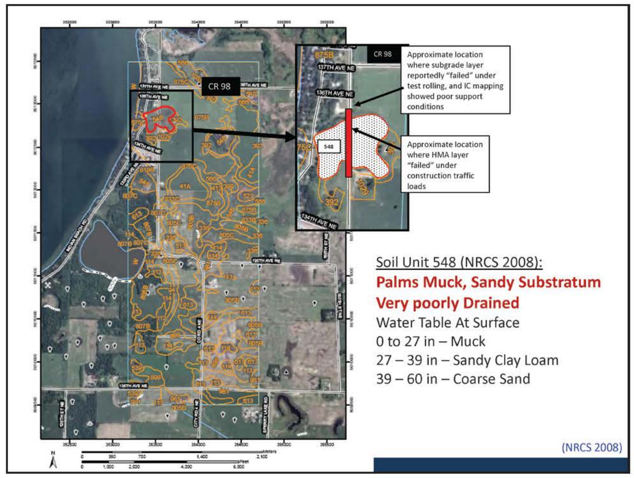

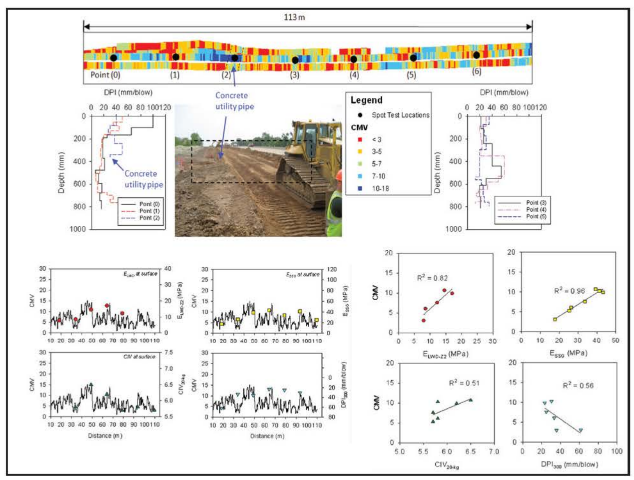

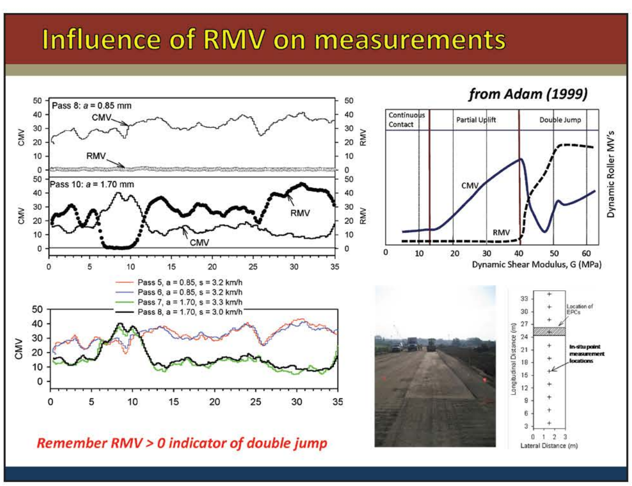

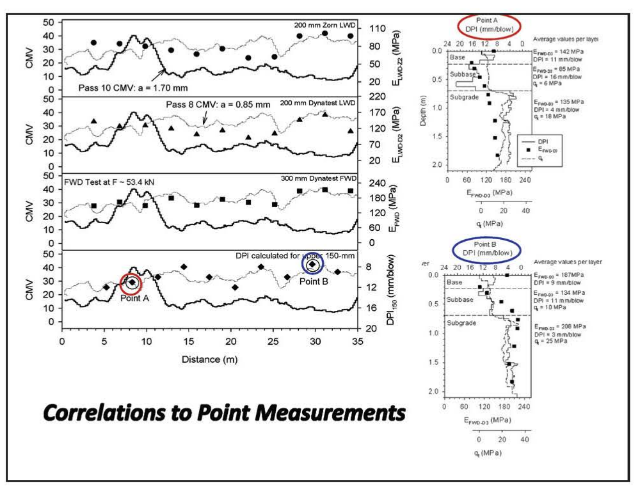

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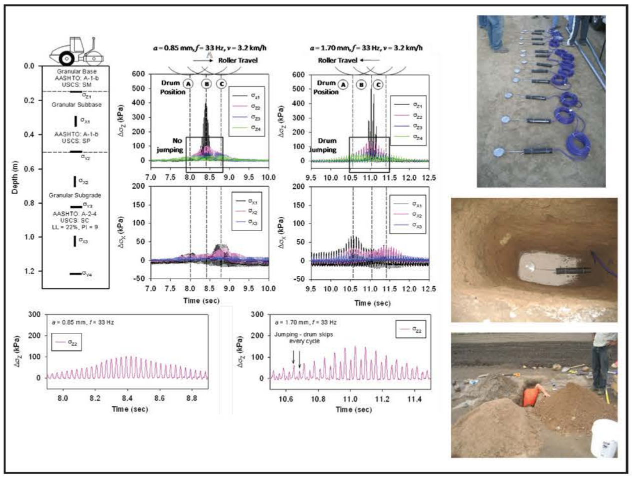

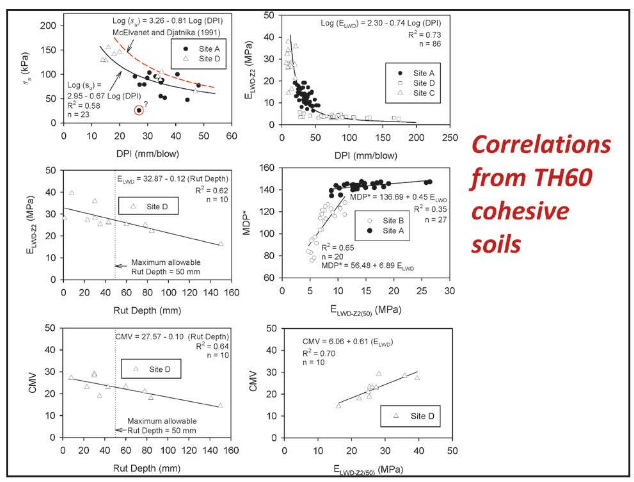

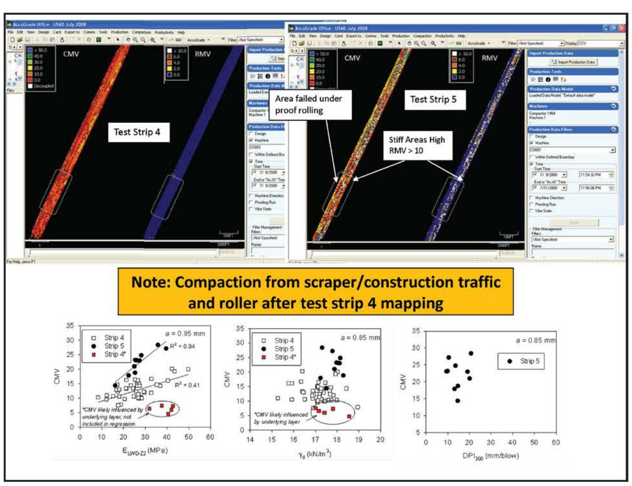

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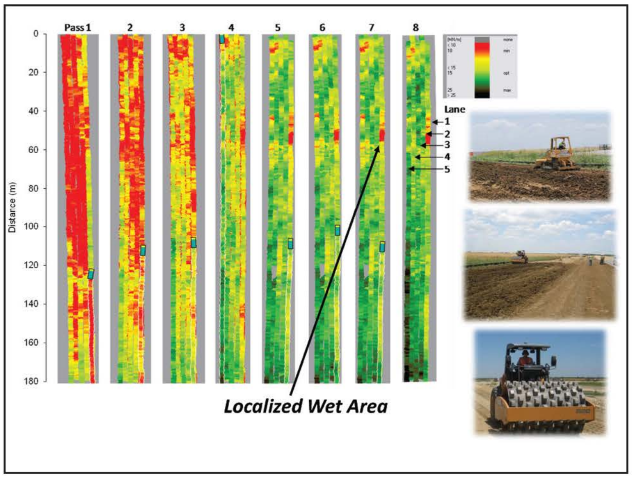

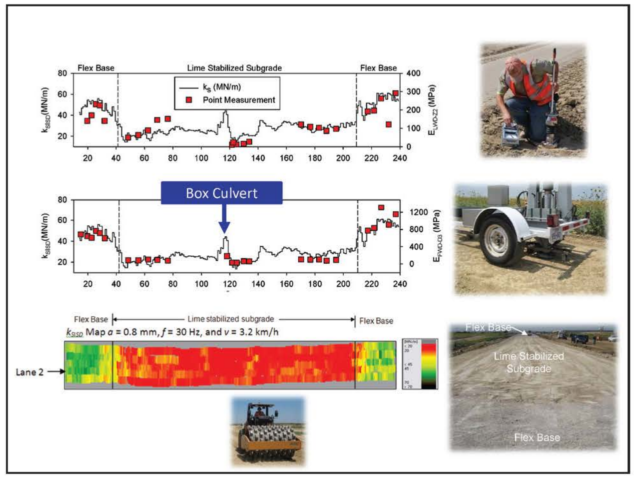

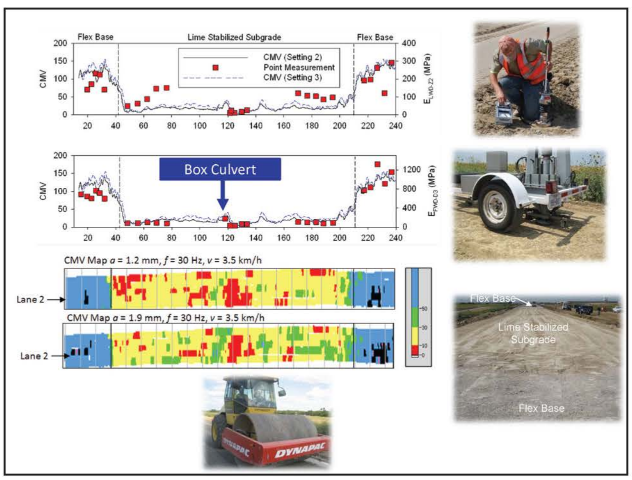

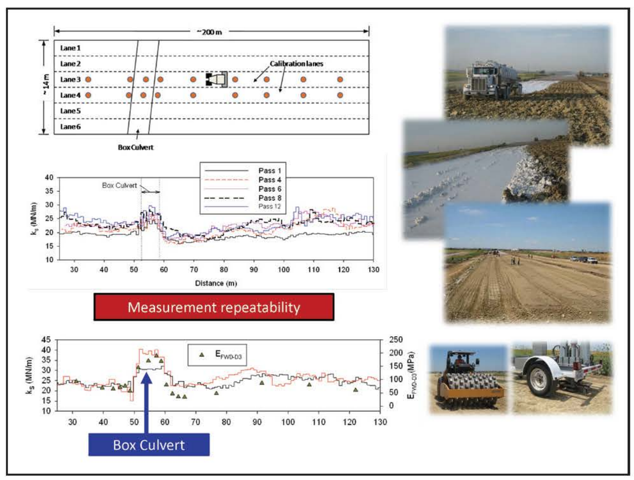

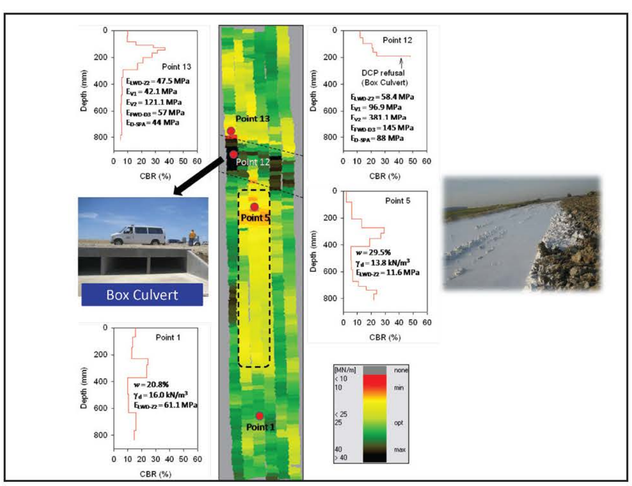

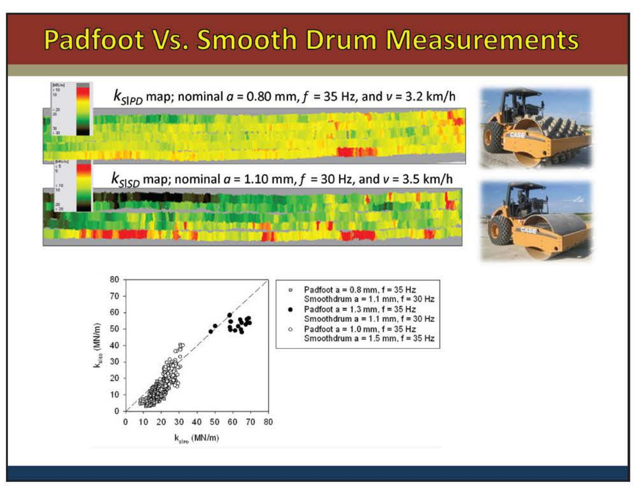

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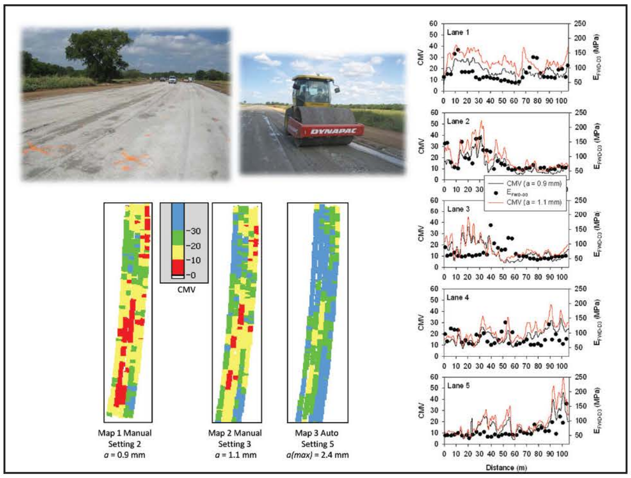

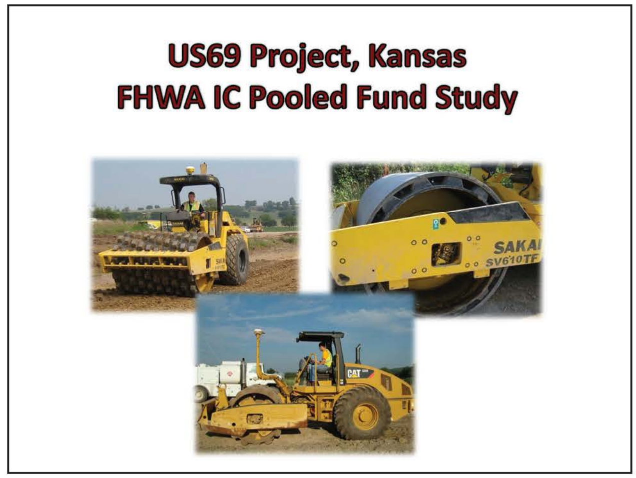

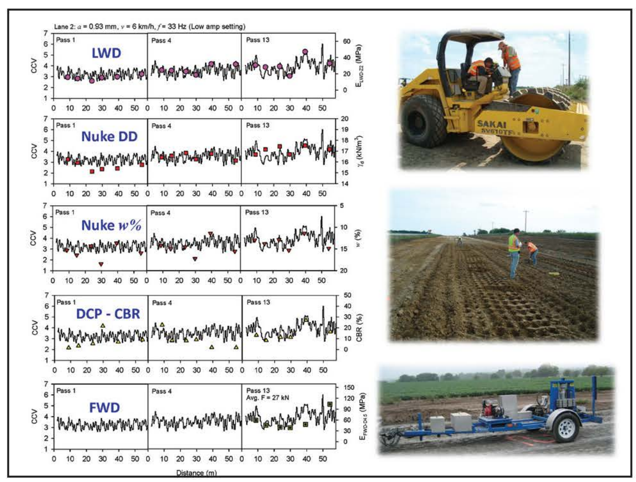

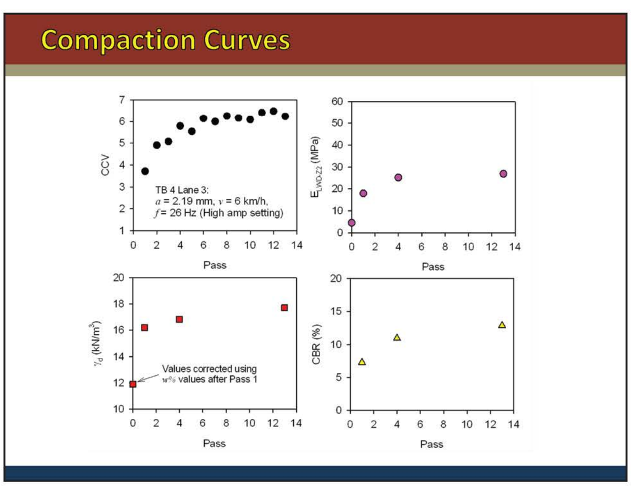

David J. White,
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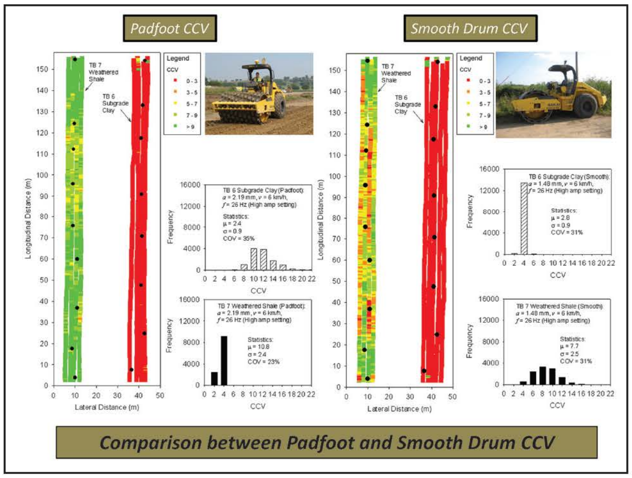


Mn/DOT's Experience with LWD Implementation

Rebecca Embacher

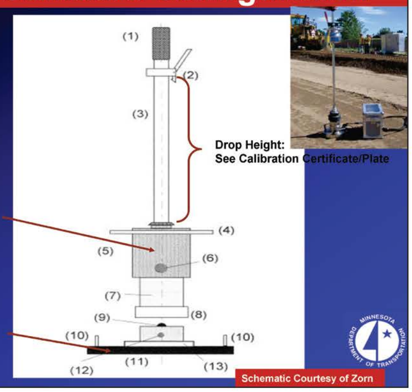
Mn/DOT's Experience with LWD Implementation

Intelligent Construction for Earthworks
April 14, 2009
Sheraton Hotel
West Des Moines, Iowa

Tim Andersen
Rebecca A. Embacher

Mn/DOT LWD Standard Configuration

- Currently Support Zorn LWD
- 27 Zorn LWDs
- Standard Configuration



Schematic Courtesy of Zorn

LWD Quality Compaction Projects

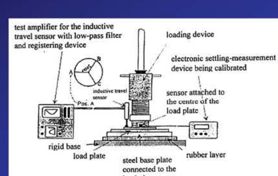
Year	Number of Projects
2007	9
2008	20
2009	10+ +Stimulus Package

Mn/DOT's Current Calibration Guidelines

- Submittal
  - Test Institute (e.g., Zorn)
  - Unable to pass repeatability testing
  - Operating parts require repair/replacement
- Measure stress under the load plate
  - Standard Pressure = 0.20 MPa
  - Force = 6.28 kN
  - Drop Height ≈ 54 cm
  - Load / Plate = 10 kg / 200 mm

Calibration Issues

- Recommended Intervals:
  - Annually
  - 10,000 measurement, but at least in every 2nd yr.
- 2009 Calibration Costs
  - Shipping: $1450
  - Calibration: $550
  - Refurbishment: $200
  - TOTAL: $2200/Unit
  - Annually: $59,400



Repeatability Testing

- Completed:
  - Annually
  - Immediately upon receipt of newly purchased device
  - After Calibration by Test Institute
  - Measurements no longer repeatable or are questionable
- Deflection Range
  - Polyurethane / Neoprene Pads
  - 0.25 mm, 0.8 mm, 1.5 mm, 2.3 mm

Mn/DOT's Experience with LWD Implementation

Rebecca Embacher

Repeatability Testing

Pad Configuration	Temp. (°C)	RH (%)	Sequence Number	Smart Card Test No.	Test Date	Test Time	S1 (mm)	S2 (mm)	S3 (mm)	Mean S (mm)	Evd [MN/m²]	Standard Deviation (mm)	Std. Dev (mm)	Smax (mm)	Smin (mm)	Smean (mm)	CoV
BBP1-A	22	24	Seating	1	4/1/2009	0.36115741	0.186	0.186	0.186	0.186	161.29						
			1	2	4/1/2009	8:40	0.185	0.188	0.182	0.185	162.2	0.002	0.004	0.188	0.175	0.183	2.0%
			2	3	4/1/2009	8:41	0.185	0.184	0.184	0.184	163.0	0.001					
			3	4	4/1/2009	8:41	0.182	0.180	0.175	0.179	167.6	0.004					
ACLA5-A	22	24	Seating	5	4/1/2009	0.36291667	0.729	0.741	0.741	0.737	40.7056						
			1	6	4/1/2009	8:43	0.737	0.739	0.739	0.738	40.7	0.001	0.003	0.744	0.737	0.740	0.3%
			2	7	4/1/2009	8:43	0.737	0.744	0.740	0.740	40.5	0.004					
			3	8	4/1/2009	8:43	0.742	0.742	0.743	0.742	40.4	0.001					
ACLA5/4-A			Seating	9	4/1/2009	0.36453704	1.441	1.463	1.46	1.455	20.6186						
			1	10	4/1/2009	8:45	1.458	1.467	1.462	1.462	20.5	0.005					0.6%
ACLA18-A																	0.5%

Smax-Smin	<=0.04mm	Smean-S1	Smean-S2	Smean-S3	S1: <=0.02	S2: <=0.02	S3: <=0.02	Avg. (Smean-Si)	New LWD Pad Spmean (mm)	<=0.02	|Spmean-Smean| (mm)
	0.04				0.03					0.04	
0.013	Pass	0.002	0.005	0.001	Pass	Pass	Pass	0.003	**0.188**	Pass	0.005
		0.002	0.001	0.001	Pass	Pass	Pass				
		0.001	0.003	0.008	Pass	Pass	Pass				
0.007	Pass	0.003	0.001	0.001	Pass	Pass	Pass	0.002	**0.745**	Pass	0.005
		0.003	0.004	0.000	Pass	Pass	Pass				
		0.002	0.002	0.003	Pass	Pass	Pass				
0.029	Pass	0.010	0.001	0.006	Pass	Pass	Pass	0.007	**1.465**	Pass	0.003
		0.007	0.008	0.002	Pass	Pass	Pass				
		0.008	0.019	0.001	Pass	Pass	Pass				
0.035	Pass	0.024	0.002	0.003	Pass	Pass	Pass	0.008	**2.239**	Pass	0.025
		0.005	0.011	0.010	Pass	Pass	Pass				
		0.003	0.003	0.011	Pass	Pass	Pass				

Repeatability Summary – All Passing

		Average					
Pad	Sample Size	Standard Deviation (mm)	Smean (mm)	CoV (%)	Smax-Smin (mm)	(Smean-Si) (mm)
1BBP1-A	26	0.004	0.189	2.409	0.013	0.004
2ACLA5-A	26	0.004	0.747	0.565	0.013	0.003
3ACLA5/4-A	26	0.006	1.461	0.388	0.017	0.004
4BBP2-A	23	0.009	2.090	0.409	0.026	0.007
5ACLA18-A	26	0.008	2.226	0.355	0.025	0.006

Quality Compaction – Deflection Method

- Optimum Moisture Content
  - Standard Proctor
  - Except:
    - Granular: EOMC or 1-pt Proctor Density Method
    - Non-Granular: 1-pt Standard Proctor Density Method
- Passing Compaction
  - $\delta \leq 1.10$*LWD-TV
- Re-Evaluate LWD-TV
  - >20% δ's ≤ 0.8*LWD-TV
  - Consistently Failing Results

http://www.dot.state.mn.us/materials/gradingandbase

LWD Test Depth / Sequence

Material Type	LWD Test Depth[1]
Granular Soils	≤ one-half lift thickness[2]
Granular Base / Stabilization Layer	0 mm (compaction surface)
Non-Granular Soils	
Compacted with Padfoot Roller	Bottom of deepest indentation of the padfoot penetration.
Compacted with Smooth-Drum Roller	Compaction Surface (0 mm)

- Seating: Drops 1 – 3
- Test: Drops 4 – 6

Note 1— The influence depth is approximately 1 to 1.5 times the plate diameter, consequently, deflection measurements obtained for lifts less than this depth will be a composite deflection measurement.
Note 2— Complete test at compaction surface (0 mm) for cases where disturbance effects exist (i.e., deflection measurements increase, due to disturbance caused by the test, from that observed at the surface).

LWD Target Value Establishment

- LWD – TV = Deflection instead of Modulus
- Two Options
  - Calibration Areas
  - Comparison Testing

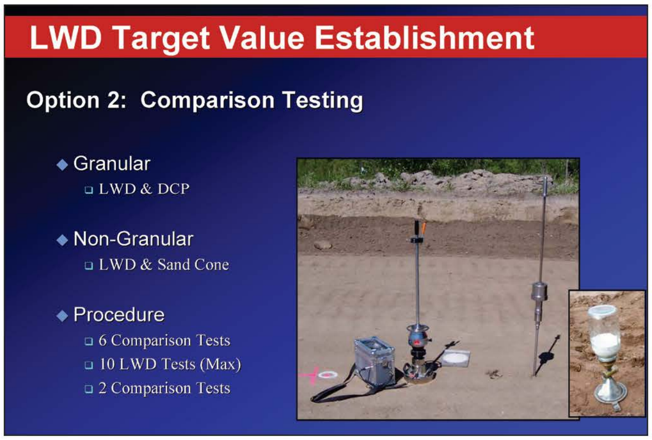
LWD Target Value Establishment

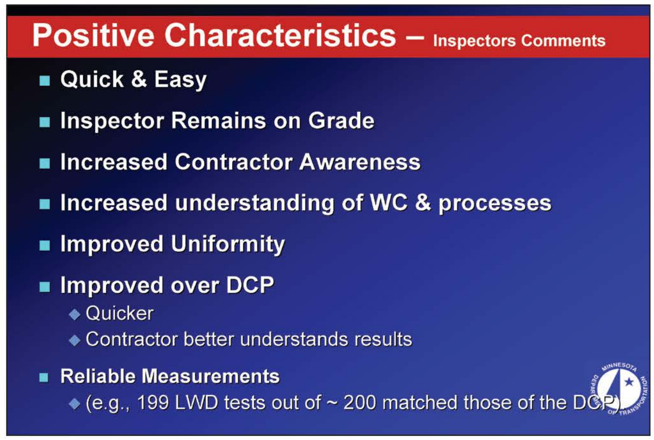
Option 1: Calibration Area

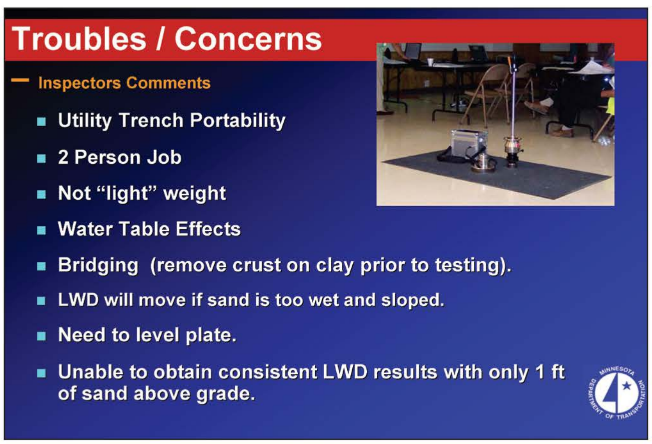
- 300 ft x Embankment Width x 4 ft
- 65% to 95% optimum moisture content
- LWD-TV = $\Delta\delta$ < 10% w/ repeated roller passes
- New Calibration Area
  - ± 2% MC of calibration area
  - Varying material properties

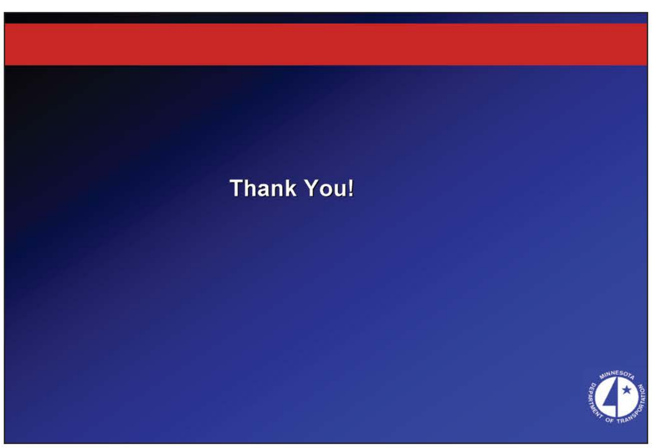
Mn/DOT's Experience with LWD Implementation

Rebecca Embacher



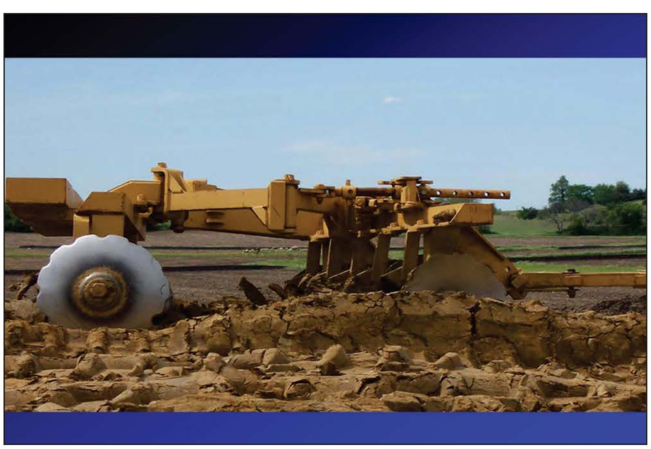


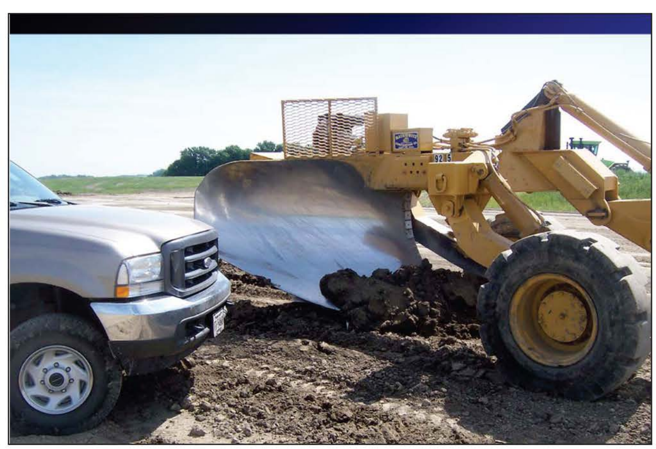




Mn/DOT's Experience with LWD Implementation

Tim Andersen





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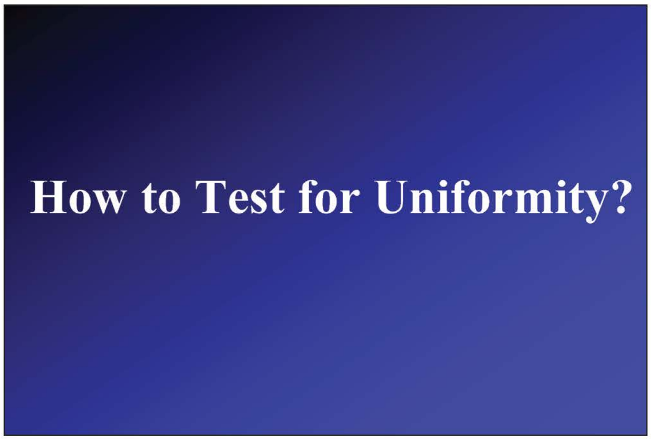
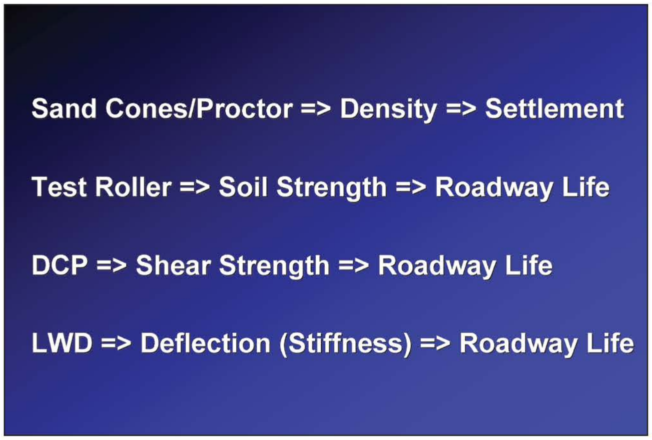




Mn/DOT's Experience with LWD Implementation

Tim Andersen

Proofing Layers

Granular Materials (Meeting Spec. 3149)	
Embankment Materials Height	Proof Layer Designation
≤ 2 feet	top of embankment height
> 2 feet & ≤ 4 feet	mid point & top of embankment height
> 4 feet	successive 2 foot layers

Quality Assurance (QA) Requirements

- Observation of final proof layer IC-MV
- Review and approve Contractor's Weekly QC Report
- Stiffness Measurement
  - Light Weight Deflectometer (LWD)
- Test Rolling @ Top of Subgrade

Light Weight Deflectometer (Model: Zorn ZFG2000)

IC Lessons Learned: *What Worked*

- Real-Time Results (IC and LWD)
- Increased
  - Compaction Uniformity
  - Inspector Safety
  - Grade Control
  - Speed Control
  - Record Keeping
  - Planning

IC Lessons Learned: *What Worked*

- Operators learn how to make better decisions
  - Pass/Fail Proof Rolling
  - Moisture Control
  - Soft areas identified and corrected earlier

Lessons Learned: *Problems Encountered*

- Data Loss
  - Storage Media not saving roller data.
  - Stolen Laptop
- Inaccurate GPS readings on IC roller.
- Base stations not correctly setup.
- Measurement value range (scale) not adequately reflecting range from "soft" to "stiff".
- Support and training issues
  - Manufacturer to the Contactor

Lessons Learned: *Problems Encountered*

- Data Management
  - Massive Data Set
  - Utilization
  - Organization
  - Generates large amounts of printout maps
- Roller Operator Requirements
  - Increased communication to roller operator is needed
  - Computer Literate
  - Educated Operators
    - Bored and Loose Interest

Mn/DOT's Experience with LWD Implementation

Tim Andersen

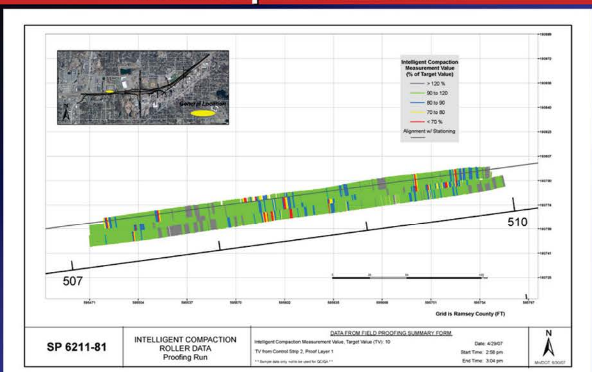
Lessons Learned: *Problems Encountered*

- **Data Gaps**
- **Filtering of invalid data**
  - Operator Screen
  - Printed Maps
  - Valid and Invalid data provided in ASCII Files
- **Need for certification of devices**
  - Operation Parameters
  - Repeatability
  - System working

Lessons Learned: *Problems Encountered*

- **Map Printing**
  - Difficult
  - Alignment often not included
  - Includes valid and invalid data
- **Too much technology coming too fast!**

Ideal Map from Roller



Lessons Learned: *Problems Encountered*

- **IC Roller is "mapper" not a "packer"**
- **Proofing Preparation**
  - Limits 'Workable' Areas
  - Cuts off Haul Roads

Potential IC Projects

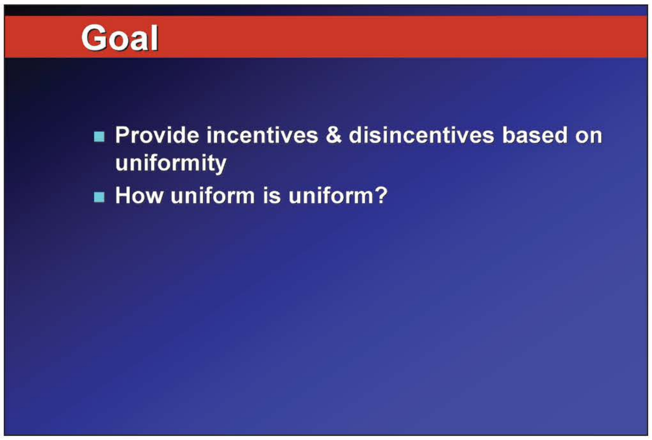
- **2009**
  - CSAH 22, Olmsted County
  - Select Stimulus Package Projects
    - TH 169 and I-494
    - TH 610
- **2010**
  - CSAH 10, Olmsted County
  - Paynesville Bypass (TH 23)
  - Central Corridor (LRT)

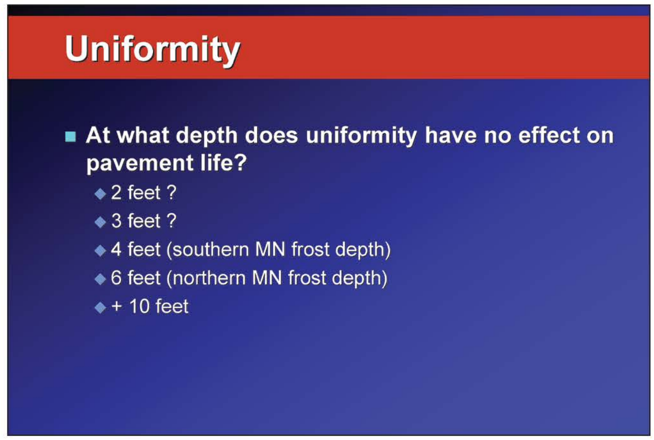
Future Granular IC Spec

- IC with Test Rolling & QC Testing
  - 2 proof layers
    - Base map & top of subgrade
- IC with QC Testing
  - 5 proof layers
  - Δ Ave MV between roller passes on 4 proof layers
  - Δ Ave MV between 3 proof layers
- IC with QC Testing
  - 2 proof layers
- IC with out QC Testing
  - 2 proof layers

Mn/DOT's Experience with LWD Implementation

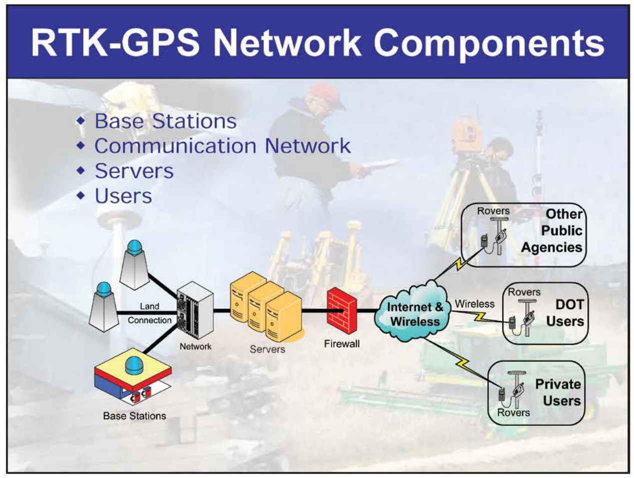
Tim Andersen

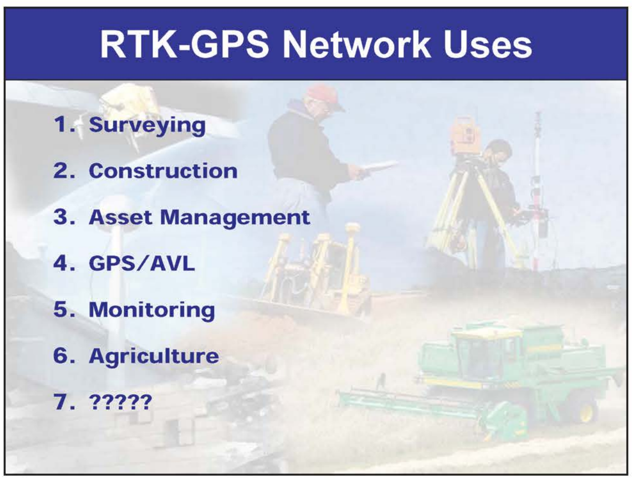


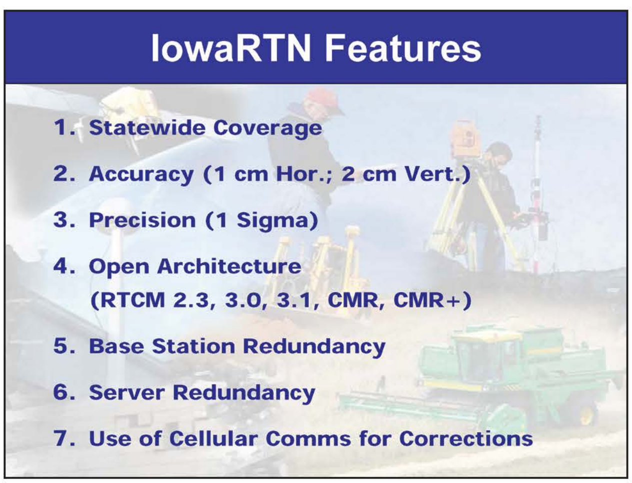


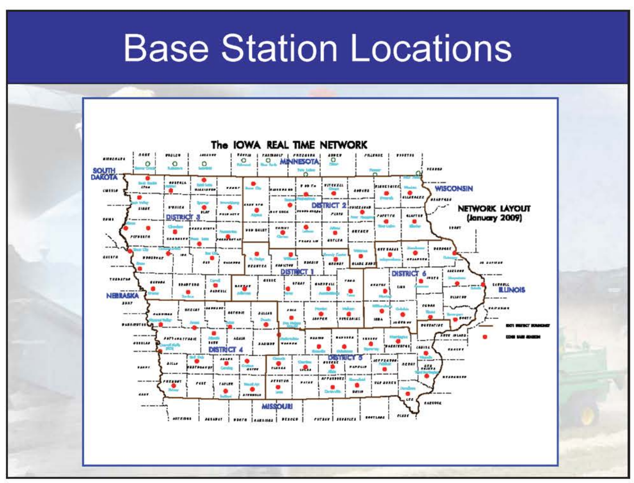
Iowa Real Time Network (IowaRTN)

Michael Jackson









Iowa Real Time Network (IowaRTN)

Michael Jackson

Project Schedule

January, 2008 -
Contract Executed w/ Leica Geosystems

July, 2008 -
Base Station Deployment Begins

November, 2008 -
Completion of Base Station Deployment

December, 2008 -
Network Acceptance Testing

January, 2009 -
Training

Project Schedule

February 2, 2009 -
IowaRTN activated for use

February 28, 2009 -
196 Users Registered
350 Rovers Registered for use

Preparing to Use the IowaRTN

Need a receiver (rover) that, at a minimum, can:

- Connect to the internet via cell phone or cell modem
  Note: The network is independent of cell service provider. Select the provider with best service in your area!
- Send a NMEA message with account username and password, or has NTRIP functionality
- Can utilize RTCM 2.3, RTCM 3.x, CMR or CMR+ message formats

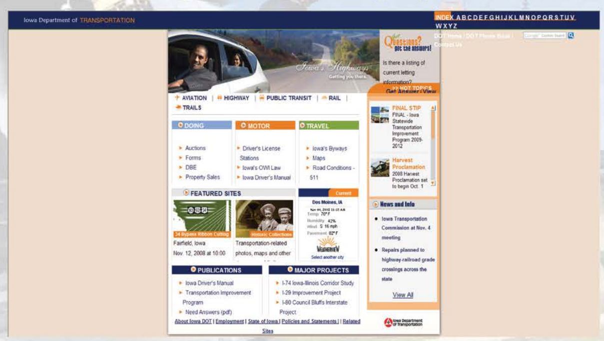
Note:

All users are strongly encouraged to run the most recent firmware for the rover/equipment they are using.

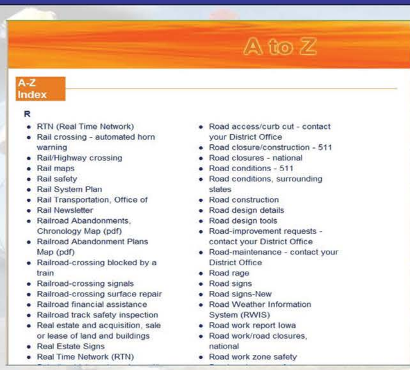
For machine control (construction and agricultural) or project areas in cell service voids, solutions exist to provide on-site radio broadcast of baseline and network solutions.

Please make sure you have a navigated position on your receiver prior to making connection with the network.

Iowa DOT Web Site
(www.iowadot.gov)

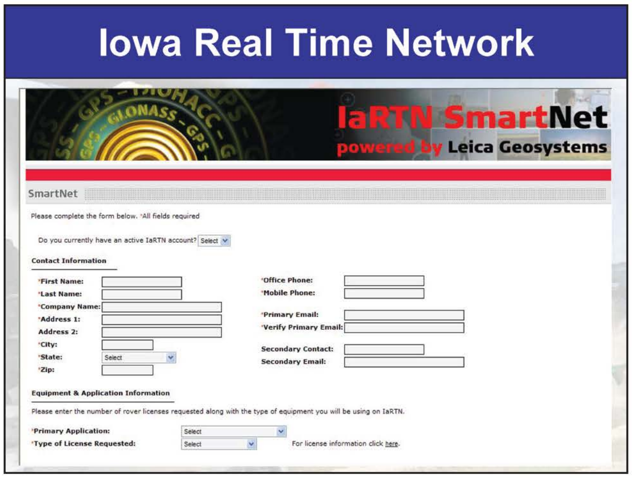


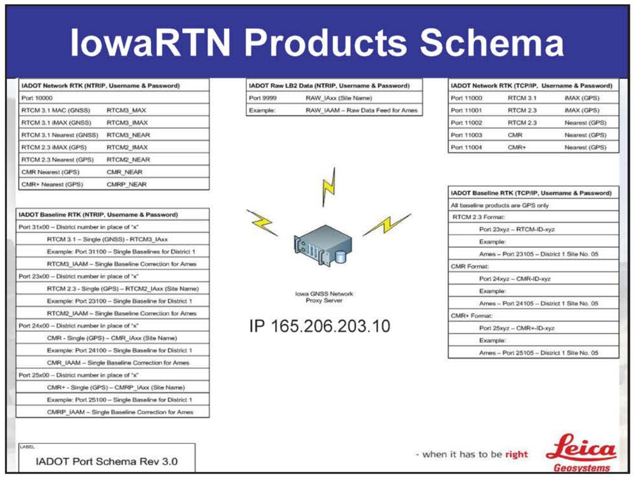
Web Site Index



- RTN (Real Time Network)
- Rail crossing - automated horn warning
- Rail/Highway crossing
- Rail maps
- Rail safety
- Rail System Plan
- Rail Transportation, Office of
- Rail Newsletter
- Railroad Abandonments, Chronology Map (pdf)
- Railroad Abandonment Plans Map (pdf)
- Railroad-crossing blocked by a train
- Railroad-crossing signals
- Railroad-crossing surface repair
- Railroad financial assistance
- Railroad track safety inspection
- Real estate and acquisition, sale or lease of land and buildings
- Real Estate Signs
- Real Time Network (RTN)
- Road access/curb cut - contact your District Office
- Road closure/construction - 511
- Road closures - national
- Road conditions - 511
- Road conditions, surrounding states
- Road construction
- Road design details
- Road design tools
- Road-improvement requests - contact your District Office
- Road-maintenance - contact your District Office
- Road rage
- Road signs
- Road signs-New
- Road Weather Information System (RWIS)
- Road work report Iowa
- Road work/road closures, national
- Road work zone safety

Iowa Real Time Network


Iowa Real Time Network
IaRTN SmartNet
powered by Leica Geosystems
SmartNet
Please complete the form below. *All fields required
Do you currently have an active IaRTN account? Select
Contact Information
*First Name:
*Last Name:
*Company Name:
*Address 1:
Address 2:
*City:
*State: Select
*Zip:
*Office Phone:
*Mobile Phone:
*Primary Email:
*Verify Primary Email:
Secondary Contact:
Secondary Email:
Equipment & Application Information
Please enter the number of rover licenses requested along with the type of equipment you will be using on IaRTN.
*Primary Application: Select
*Type of License Requested: Select
For license information click here.


IowaRTN Products Schema
IADOT Network RTK (NTRIP, Username & Password)
Port 10000
RTCM 3.1 MAC (GNSS) RTCM3_MAX
RTCM 3.1 iMAX (GNSS) RTCM3_IMAX
RTCM 3.1 Nearest (GNSS) RTCM3_NEAR
RTCM 2.3 iMAX (GPS) RTCM2_IMAX
RTCM 2.3 Nearest (GPS) RTCM2_NEAR
CMR Nearest (GPS) CMR_NEAR
CMR+ Nearest (GPS) CMRP_NEAR
IADOT Baseline RTK (NTRIP, Username & Password)
Port 31x00 – District number in place of "x"
RTCM 3.1 – Single (GNSS) - RTCM3_IAxx
Example: Port 31100 – Single Baselines for District 1
RTCM3_IAAM – Single Baseline Correction for Ames
Port 23x00 – District number in place of "x"
RTCM 2.3 - Single (GPS) – RTCM2_IAxx (Site Name)
Example: Port 23100 – Single Baseline for District 1
RTCM2_IAAM – Single Baseline Correction for Ames
Port 24x00 – District number in place of "x"
CMR - Single (GPS) – CMR_IAxx (Site Name)
Example: Port 24100 – Single Baseline for District 1
CMR_IAAM – Single Baseline Correction for Ames
Port 25x00 – District number in place of "x"
CMR+ - Single (GPS) – CMRP_IAxx (Site Name)
Example: Port 25100 – Single Baseline for District 1
CMRP_IAAM – Single Baseline Correction for Ames
IADOT Raw LB2 Data (NTRIP, Username & Password)
Port 9999 RAW_IAxx (Site Name)
Example: RAW_IAAM – Raw Data Feed for Ames
Iowa GNSS Network
Proxy Server
IP 165.206.203.10
IADOT Network RTK (TCP/IP, Username & Password)
Port 11000 RTCM 3.1 iMAX (GPS)
Port 11001 RTCM 2.3 iMAX (GPS)
Port 11002 RTCM 2.3 Nearest (GPS)
Port 11003 CMR Nearest (GPS)
Port 11004 CMR+ Nearest (GPS)
IADOT Baseline RTK (TCP/IP, Username & Password)
All baseline products are GPS only
RTCM 2.3 Format:
Port 23xyz – RTCM-ID-xyz
Example:
Ames – Port 23105 – District 1 Site No. 05
CMR Format:
Port 24xyz – CMR-ID-xyz
Example:
Ames – Port 24105 – District 1 Site No. 05
CMR+ Format:
Port 25xyz – CMR+-ID-xyz
Example:
Ames – Port 25105 – District 1 Site No. 05
LABEL
IADOT Port Schema Rev 3.0
- when it has to be right
Leica
Geosystems


Contact Information
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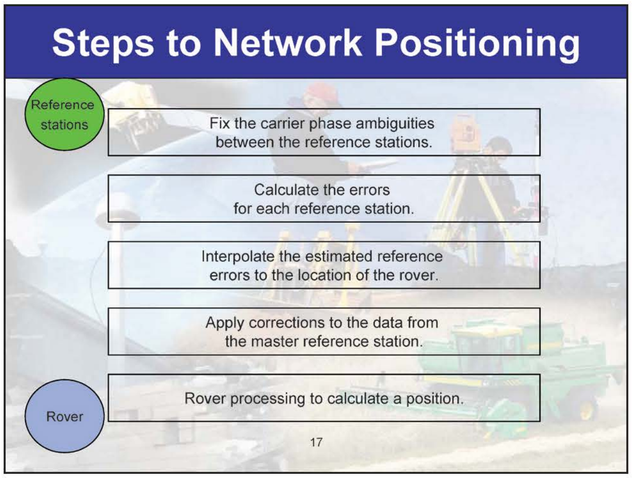
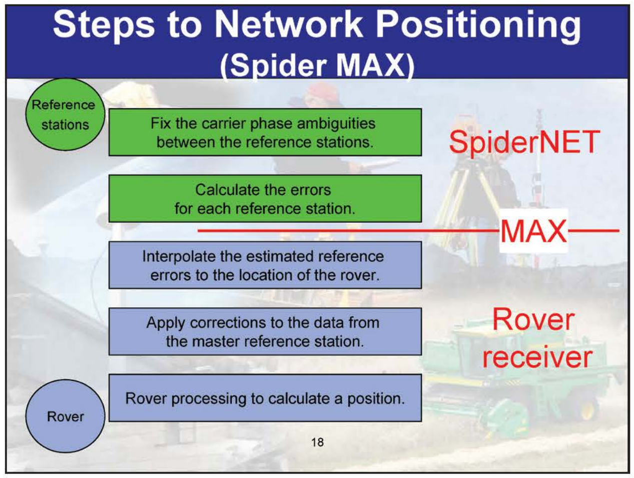
Special Projects Engineer
515-239-1192 (office)
michael.jackson@dot.iowa.gov

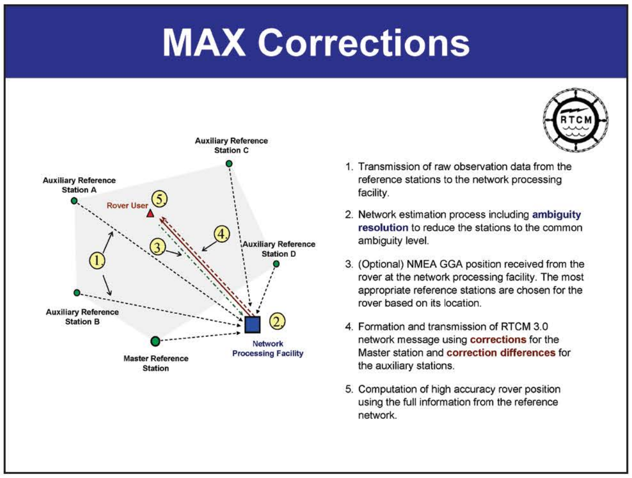

Iowa Department of Transportation
Questions?

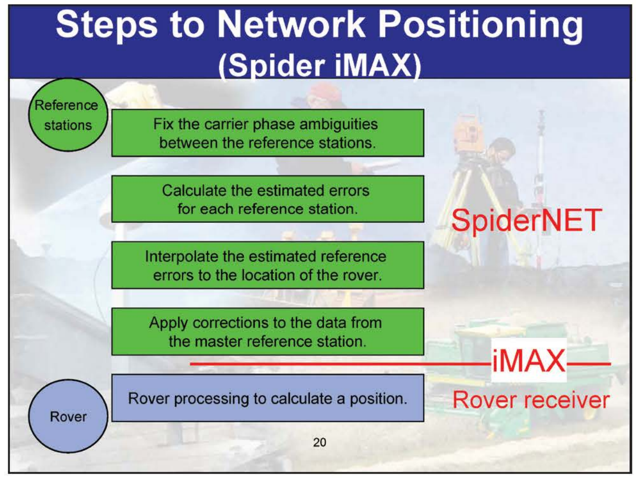

Steps to Network Positioning
Reference stations
Fix the carrier phase ambiguities between the reference stations.
Calculate the errors for each reference station.
Interpolate the estimated reference errors to the location of the rover.
Apply corrections to the data from the master reference station.
Rover
Rover processing to calculate a position.
17

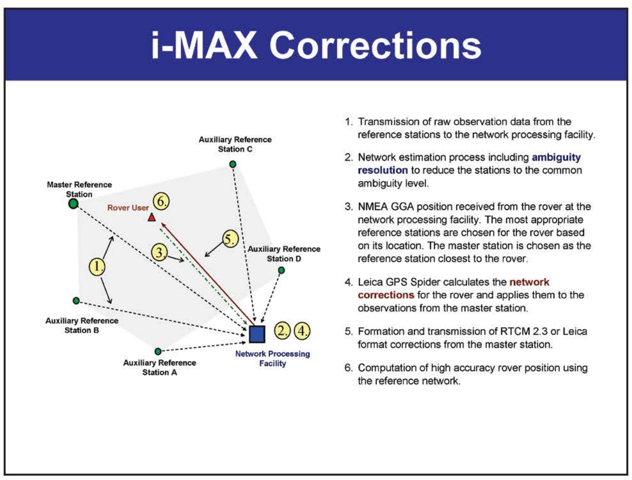

Steps to Network Positioning
(Spider MAX)
Reference stations
Fix the carrier phase ambiguities between the reference stations.
Calculate the errors for each reference station.
SpiderNET
MAX
Interpolate the estimated reference errors to the location of the rover.
Apply corrections to the data from the master reference station.
Rover receiver
Rover
Rover processing to calculate a position.
18

Iowa Real Time Network (IowaRTN)

Michael Jackson







GPS Technology in Planning, Design, and Construction Delivery; GPS Automatic Grade Control Systems, Engineering Distance Education; NCHRP 10-77

Jeff Hannon, Charles Jahren, and David White

Iowa State University
Iowa Department of Transportation
The University of Southern Mississippi

Intelligent Construction for Earthworks
Sheraton Hotel, West Des Moines, Iowa
April 14–16, 2009

John Jeffrey Hannon
Associate Professor
The University of Southern Mississippi
School of Construction
Hattiesburg//Gulfport//Long Beach, MS

EERC EARTHWORKS ENGINEERING RESEARCH CENTER
ctre Center for Transportation Research and Education

The University of Southern Mississippi
Golden Eagles
Colors: Black and Gold

The University of Iowa
Tiger Hawks
Colors: Black and Gold

In 2004, Iowa claimed that the Southern Mississippi Golden Eagles logo, introduced in January 2003, was too similar to the Hawkeyes' Tiger Hawk logo, which has been in use since 1979. Southern Mississippi denied that there were any significant similarities and continues to use the logo.

http://www.momentummedia.com/articles/am/am1705/logo.htm

Mississippi Dept. of Transportation– Study No. 214 MDOT Implementation Plan for Global Positioning Systems (GPS) Technology in Planning, Design, and Construction Delivery

5.a.i LITERATURE REVIEW

TRB Annual Conference, Wash DC, Jan 09

Workshops/Presentations Attended:

- Curtis Clabaugh (WY DOT)-Mapping and Digital Terrain Models for Project Design
- Kevin Akin (CALtrans)-Bringing Machine Control to California DOT (Caltrans) Construction Projects
- Gerhard Pilchner (H.B. Rowe & Co.)-History of Machine Control: Contractor's View
- Ron Ciccarone (Rochester & Associates)-Regenerating Digital Terrain Data for Use with Contractor's Equipment
- Lance Brown(Kiewit Southern)-Automated Machine Control -AMG

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5.a.ii. LITERATURE REVIEW

Collection of Agency Specifications and History

1. CA Dept of Transportation
2. MN Dept of Transportation
3. IA Dept of Transportation
4. NYS Dept of Transportation

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5.a.ii. LITERATURE REVIEW
Collection of Agency Specifications and History

1. Caltrans History 2001-Present

•2001, Technology Introduced/Early Adopters (Vendors/Contractors)
•2003, Machine Guidance Committee
(Designers, Surveyors, Construction, Office Engineers--to UNDERSTAND the technology as an organization)
-what is it?
-How does it work?
-what does it mean to us?
•2005, 2nd Level Guidance: Director, AGC
•2006, Industry Capacity Expansion Plan
•2007, Pilot Projects
•Currently=> Software Application Change (can't afford everything wanted)
•Currently=> Organizational Functions/Process Work-Flow Changes (Create Policy)
•Future=> Full Adoption

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GPS Technology in Planning, Design, and Construction Delivery; GPS Automatic Grade Control Systems, Engineering Distance Education; NCHRP 10-77

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Collection of Agency Specifications and History

Caltrans Results/Early Conclusions

1. Most Issues Organizational (Change is Required)
   - Paper plans (2D) are the legal document
   - 3D design files are an INTERMEDIATE product
   - Model/digital files not part of bid documents, not required by agency at bid date
2. Discovered design software application limitations
   - Current design software is cross-section based, not model based (therefore additional processes/work is required)
3. Agency reluctance to provide electronic files
   a) additional liability
   b) digital translation issues (is there distortion?)
      - no single data format
      - different triangulation algorithms
      - iteration count of translations (XML parser problems)
   c) mindset
4. No ROI data (cost savings)

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Caltrans Results/Early Conclusions

5. Agency Employee Technological Competencies
6. Agency Employee Information handling capacity
7. Caltrans participates on DIFFERENT LEVELS, depending upon the project/Agency Resident-Design Division(decider), not mandatory
8. Caltrans uses conventional staking for the agency project Inspector (not for contractor use), requires contractor to tie digitally to the conventional stakes.
9. Caltrans ALLOWS on specific projects

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Caltrans Definition of Suitable Projects for AMG:

- Design is based upon a Digital Terrain Model (DTM)
- Earthwork quantities constitute a 'major pay item'
- GPS environment is good (line of sight to satellites)
- Required Electronic Files are available:
  (CalTrans provides to Contractor so IT can build the model)
  a) Original survey DTM
  b) Alignments and profiles
  c) Cross-sections
  d) Contour grades
  e) 2D Microstation CAD files

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Caltrans Design Software Requirements:

- Integration of 3D model, 2D CAD files, slope stake notes
- Interoperability (Import/Export in standardized formats)
- Translation issues identified and resolved
  (by software vendors/software applications)

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CalTrans Pilot Project Results:

- Increased speed of earthmoving
- CalTrans Resident Engineer valued having 3D model for problem solving
- Agency reluctance to share digital information
- Inconsistent documentation of results (MDOT DON'T MAKE THIS MISTAKE)

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CalTrans GOAL of FULL IMPLEMENTATION:

1. Management/Organizational Commitment
2. Design Every Project in 3D (3D Model)
3. Model to be included in Bid Package
4. Alter work flow processes during design, bidding, and construction
5. Identify at early stage, projects which should NOT use AMG
6. Assign responsibility for digital file maintenance
7. Mutual GPS calibration at start of projects
8. Agree on Project survey control to be used for life of project

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Caltrans 3D Model Bid Packages:

- Digital security/integrity
- Liability waivers
- Copyright protection
- Accountability for digital file management
  (revisions, changes, mistakes, alterations, etc.)

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Caltrans Unresolved:

How to synthesize 3D model, 2D CAD files, slope stake notes?? (information silos)

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Areas to address based upon Caltrans experience:

- Technological Awareness(Agency/Contractors/Vendors)
- Organizational Functions/Process Work-Flow
- Software Application Tools (3D Design)
- Legal/Mindset: Liability/sharing electronic data
- Quantitative data showing cost savings
- Agency Employee Technological Competencies
- Agency Employee Information handling capacity

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2. Mn/DOT History 2001-Present

'DOT not ready culturally, legally, philosophically for 3D design' (Barrett, 2007)

2001 P069 Software Project (Bentley GEOPAK, 3D Modeling)
2003 Pilot Project(s)
2005 Most Districts completed at least one project
2005 Machine Control Special Provision 2011 (Grading Only)
2006 Full implementation state-wide

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Mn/DOT Machine Control Special Provision 2011 (Grading Only)

Mn DOT: (1) Mandates AMG or (2) Allows AMG use

- Mandated AMG
  - Defines type of electronic data (ED) provided by agency
  - Contractor assumes responsibility for integration of ED with machines
  - Defines agency time windows for providing and upgrading ED to contractor
  - Waives delay liability and pay adjustments due to inadequate GPS signal reception
  - Specifies specific GPS hardware contractor can use (2 vendors, others by Mn/DOT approval/interoperability)
  - Specifies use of Robotic Total Stations (RTS)-No GPS in use
  - Waives guarantee of RTS ED ('for information only')
- Allows AMG Use
  - Mn/DOT does not share ED

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Mn/DOT-The success of 3D Machine Control systems relies upon several variables, including:

- The quality of the proposed construction model.
- The ability of the owner to approve and review the design.
- The ability of the operator to accurately apply the design in the field.

Conversely, the lack of tools required to create effective models leads to 3D Machine Control Systems failure and design workflow change. (Dillingham, Jensen, & Schulist, 2007)

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3. IA/DOT DS-01103 Developmental Specification 09/18/07 (Grading Only)

Two Sections:

1. Agency Responsibilities
2. Contractor Responsibilities

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IA/DOT DS-01103 Developmental Specification – 1. AGENCY Responsibilities

- Amends and takes precedence over Standard Specifications
- Allows AMG
- Plans indicate areas in which (3D) electronic surface models (ESM) are provided by agency
- Areas of project which are not covered by ESM-contractor may model at no cost to agency
- Any hardware allowed which meets grading spec tolerances
- Electronic Data provided by agency must be integrated by contractor
- Agency provides initial control/translation
- ESM provided in bidding documents
- No guarantee of agency data compatibility with contractor's data system
- Accuracy liability waiver

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IA/DOT DS-01103 Developmental Specification – 1. AGENCY Responsibilities (cont)

a. CAD Files:
  - GEOPAK TIN files representing the design surfaces.
  - GEOPAK GPK file containing all horizontal and vertical alignment information.
  - GEOPAK documentation file describing all of the chains and profiles.
  - MicroStation primary design file.
  - MicroStation cross section files.
  - MicroStation ROW data file.
  - MicroStation photogrammetry and text files.

b. Machine Control Surface Model Files:
  - ASCII format.
  - LandXML format.
  - Trimble Terramodel format.

c. Alignment Data Files:
  - ASCII format.
  - LandXML format.
  - Trimble Terramodel format.

- Agency Engineer can spot check and order re-work

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IA/DOT DS-01103 Developmental Specification –

2. CONTRACTOR Responsibilities

- Provides Engineer with GPS rover + 8 hours of training in use
- Assumes liability for all errors in use of AMG
- Agency liability waiver for errors during data conversion (between formats, transitions)
- Daily calibration of equipment
- Meet accuracy and tolerances of the Standard Specifications
- Establishment of secondary control points @ 1000 ft intervals or less by closed level loops
- Preserve all control points
- Set hubs at hinge points of x-sect ML@ 1000 ft intervals or less
- Grade stakes at other critical points
- Written Machine Control Grading Work Plan at Pre-Construction Conference
- Bid Item (LS) for GPS Machine Control Grading

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Collection of Agency Specifications and History

4. NYS/DOT EI-06-007 REVISION TO STANDARD SPECIFICATIONS:

- **Section 105-10** (Survey and Stakeout)
  - To incorporate surveying parameters and standards for quality control of positioning terrain data, and provide guidance on the appropriate interpretation of terrain data provided in contract documents.
  - Levels of precision and methods of measurement
  - Sharing of control network
  - Synchronization of survey procedures btwn agency & contractor
  - DTM liability of accuracy waiver

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Collection of Agency Specifications and History

NYS/DOT EI-06-007 REVISION TO STANDARD SPECIFICATIONS:

Section 625 (SURVEY OPERATIONS, ROW MARKERS & PERMANENT SURVEY MARKERS (Allows AMG)). This specification is revised as follows:

- To incorporate the use of new survey and automated equipment operations.
- To require the sharing of electronic engineering data, when available, between the Contractor and Department.
- To clarify which survey operations require direct oversight by a licensed Land Surveyor or Professional Engineer.
- To require the submission of a Contract Control Plan at the beginning of a construction contract which describes what control will be jointly used by the Contractor and the Department for the construction of the contract. The Contract Control Plan is intended to document which control points, datum, correction factors, and stakeout methods will be used in the field prior to beginning operations.
- To standardize engineering data processing and formats to promote sharing of that data between all stakeholders.
- To incorporate the use of CADD applications in the field for modeling construction features, determining potential conflicts, and calculating quantities.

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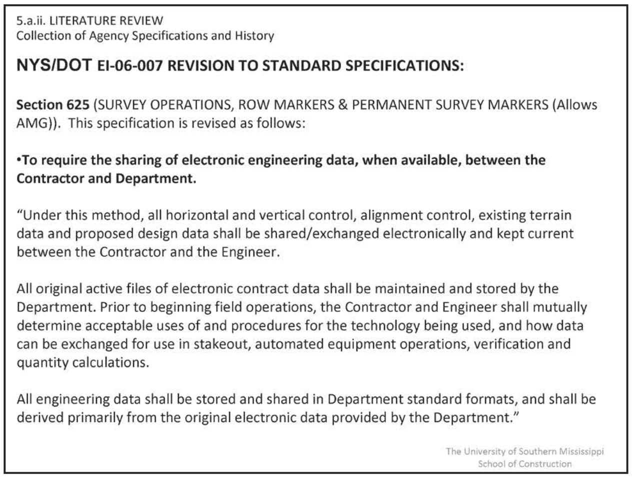


Participating State DOT Briefings

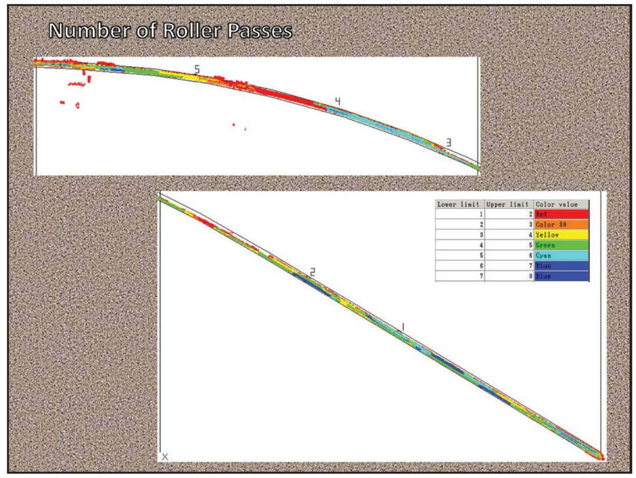
David Jared, GDOT

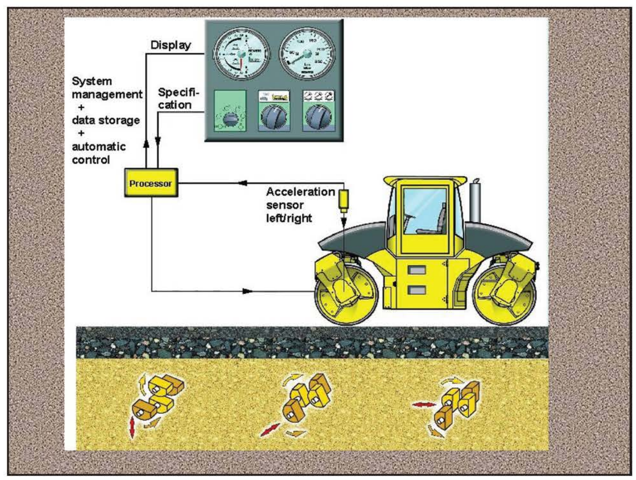
Preliminary IC Demonstrations

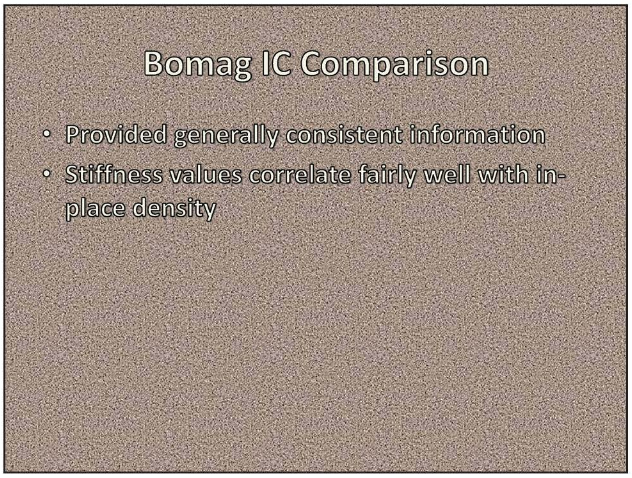
- Two demos on projects in spring 2008
  - Sakai
  - Bomag

Participating State DOT Briefings

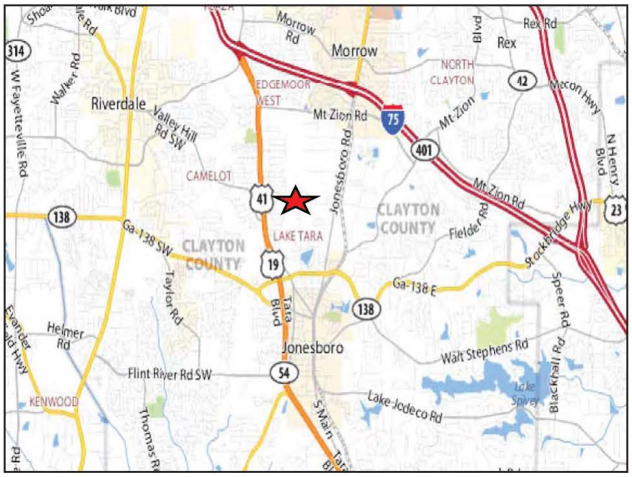
David Jared, GDOT

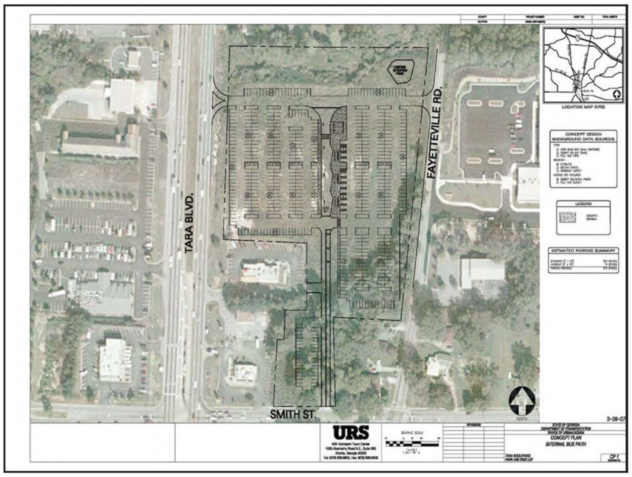




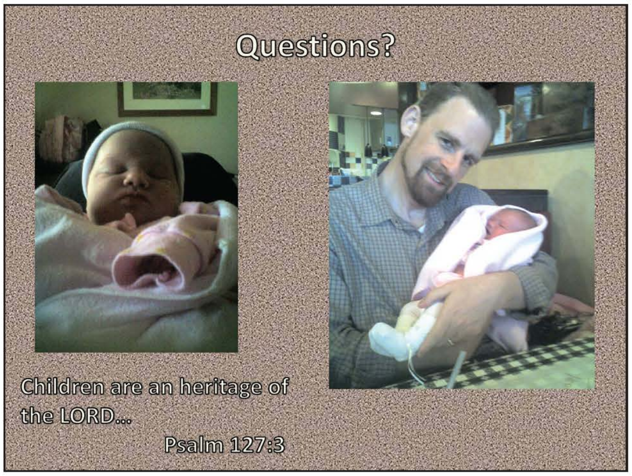

Bomag IC Comparison
• Provided generally consistent information
• Stiffness values correlate fairly well with in-place density


What's Next?
Georgia Is 1 of 13 States Participating in Three Year Pooled-Fund Study on IC…
TPF 5-(128)
Accelerated Implementation of Intelligent Compaction Technology for Embankment Soils, Aggregate Base, and Asphalt Pavement Materials


Riverdale
Morrow
Rex
CLAYTON COUNTY
LAKE TARA
Jonesboro
Mt Zion Rd
Ga-138 SW
Ga-138 E
Flint River Rd SW
Walt Stephens Rd
Lake Jodeco Rd
KENWOOD
CAMELOT
EDGEMOOR WEST
NORTH CLAYTON

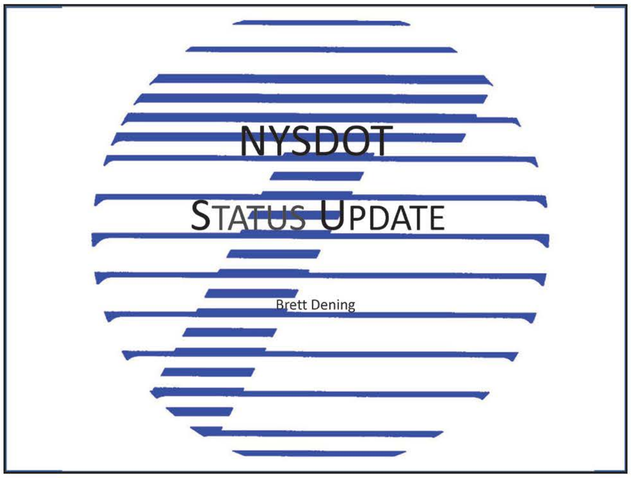

TARA BLVD.
FAYETTEVILLE RD.
SMITH ST.
URS


GPS Grading Technology
• Successfully used on pilot projects
• Two special provisions approved


Questions?
Children are an heritage of the LORD…
Psalm 127:3

Participating State DOT Briefings

Brett Dening, NYSDOT



Intelligent Compaction

- US FHWA Research Project DTFH61-07-R0032
- "Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils"
  - Location
    - US 219 in Springville, NY
  - Scope
    - 4 mile long new construction with two lanes in each traffic direction

Intelligent Compaction

- Materials
  - Granular non-cohesive soils
  - Granular subbase material
- Rollers
  - Bomag single, smooth drum IC roller.
  - Caterpillar single, smooth drum IC roller.

Alternative In-Situ Testing

- Non-Nuclear Density
  - Falling Light Weight Deflectometer (LWD)
    - Zorn
  - Soil Density Gage (SDG)
    - TransTech
  - Electronic Density Gage (EDG)
    - Electronic Density Gage L.L.C.

Automated Machine Guidance

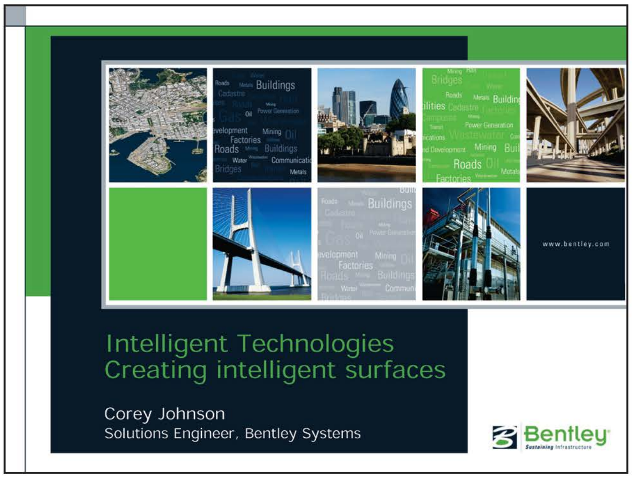
- Contractor driven

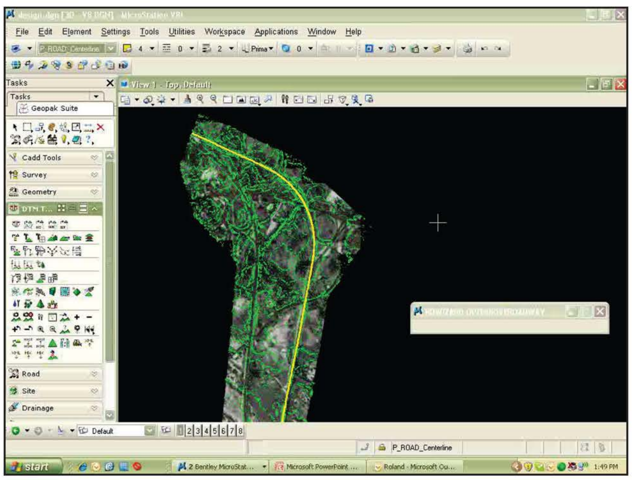
New Specification Develop

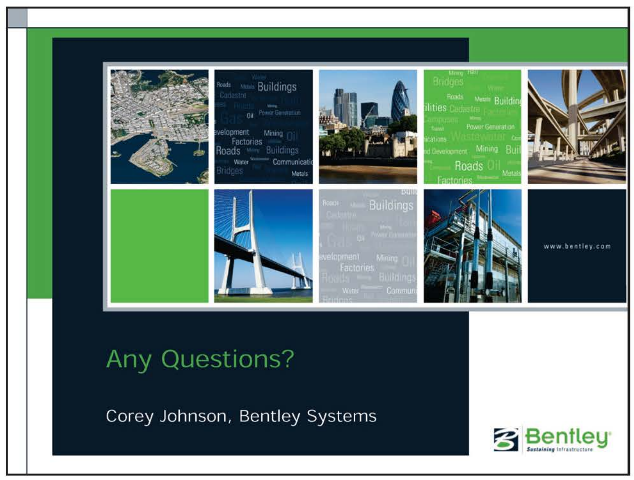
- Nothing at this time

Intelligent Technologies Creating Intelligent Surfaces

Corey Johnson, Bentley

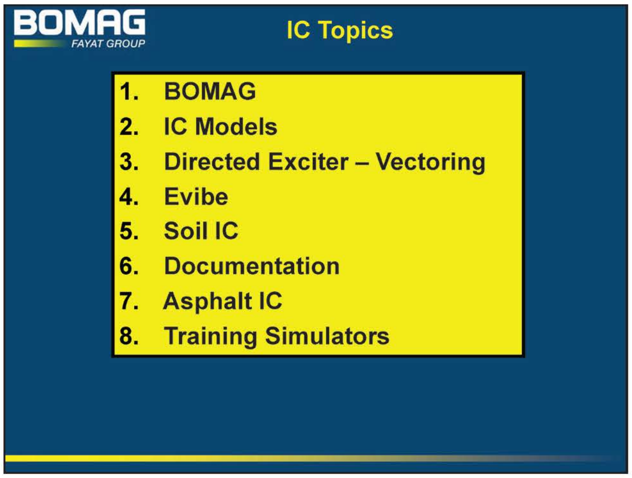


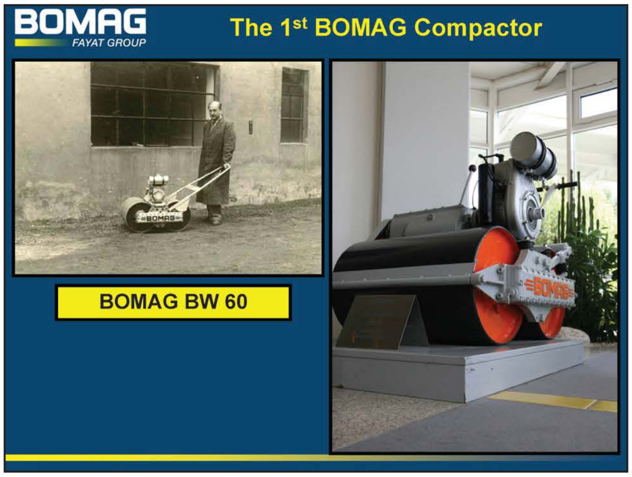


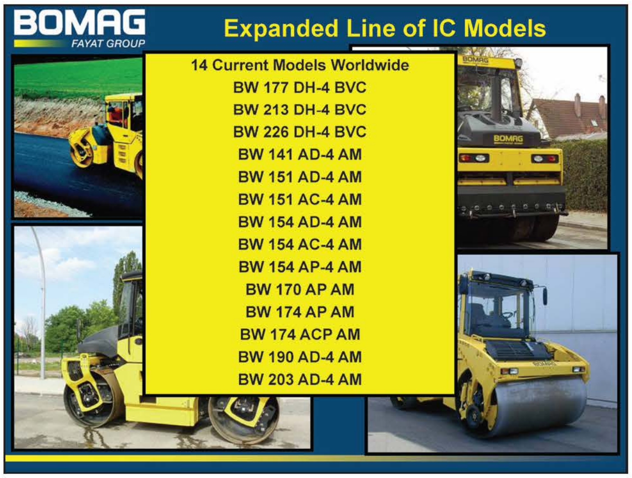


Overview of BOMAG IC Technology

Dave Dennison, BOMAG







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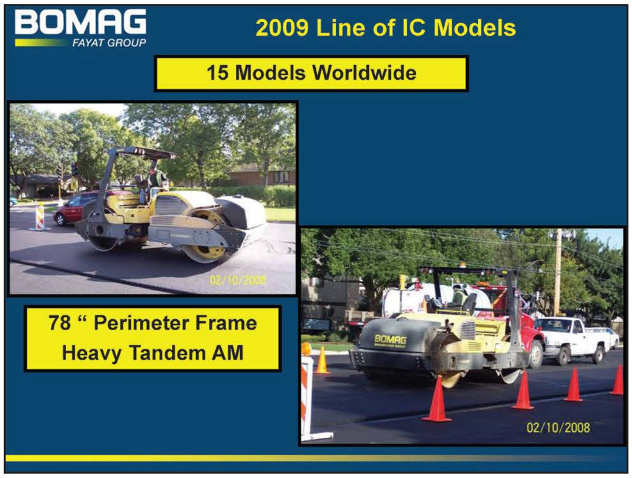

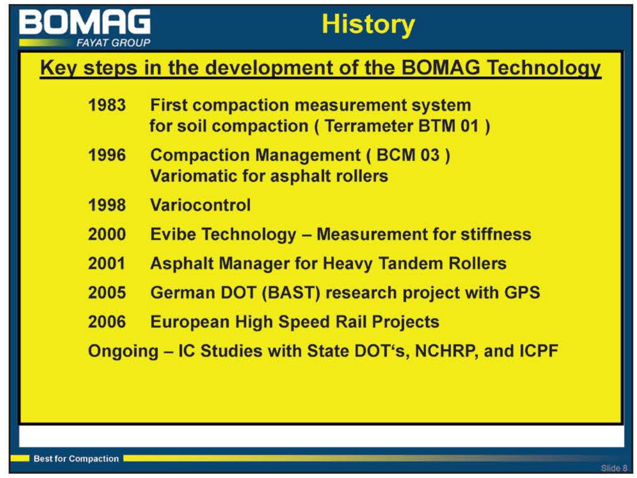

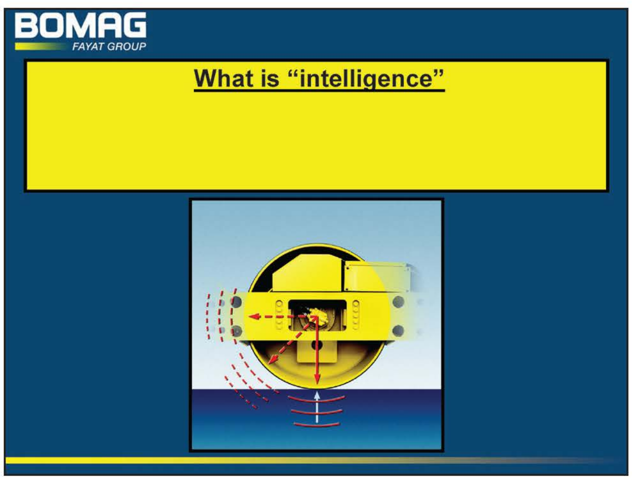

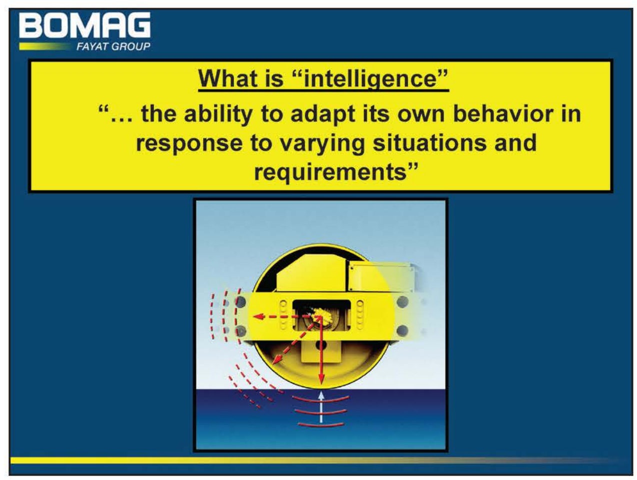

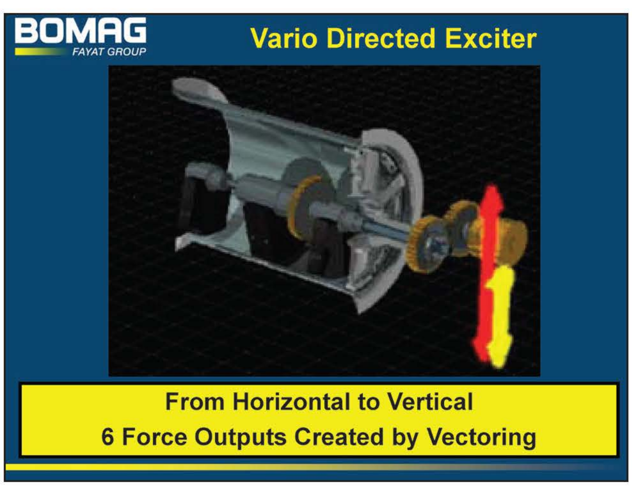

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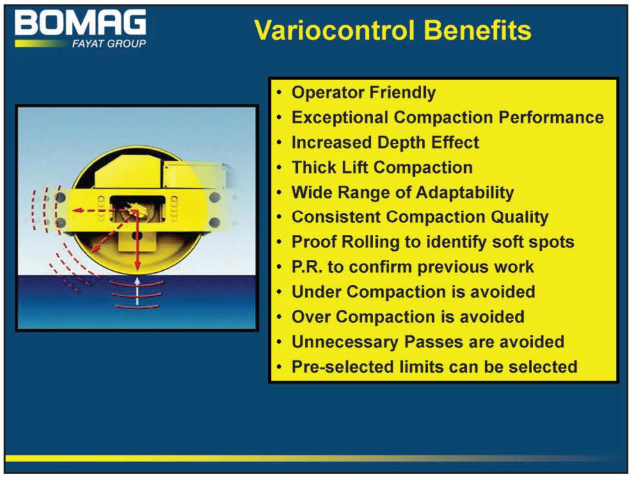

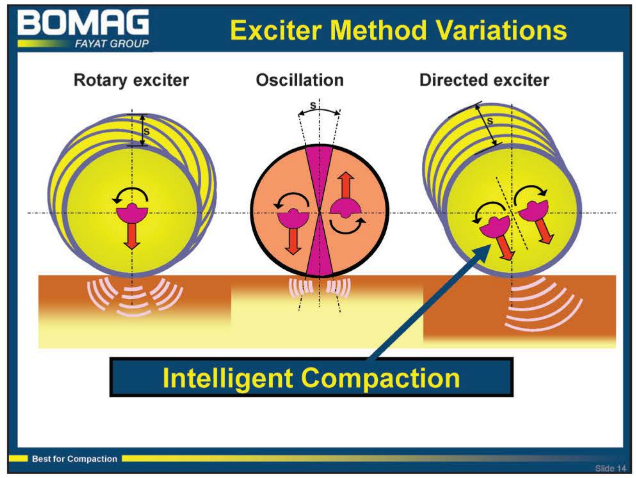

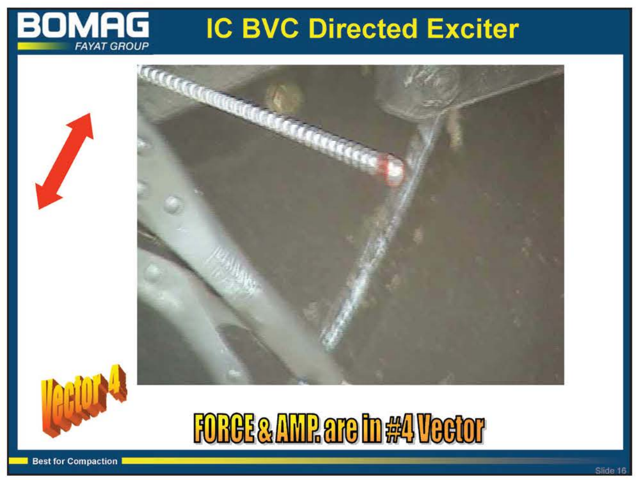

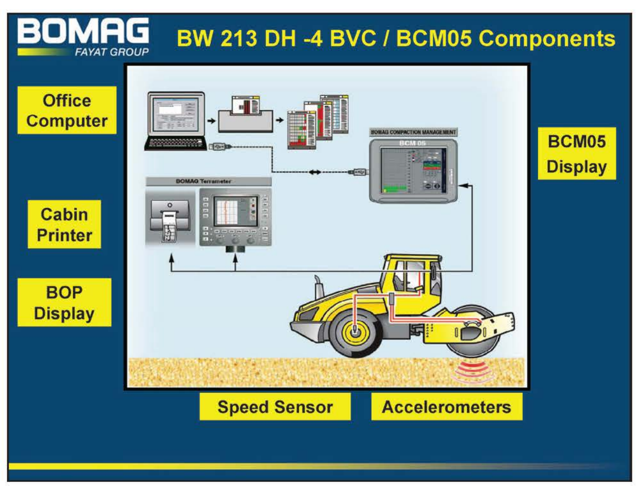

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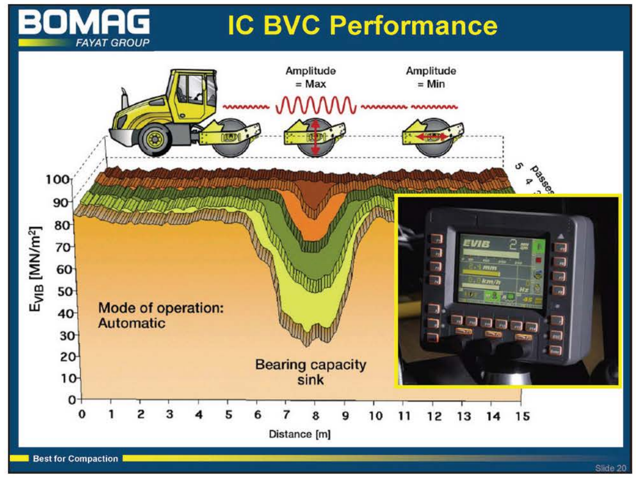

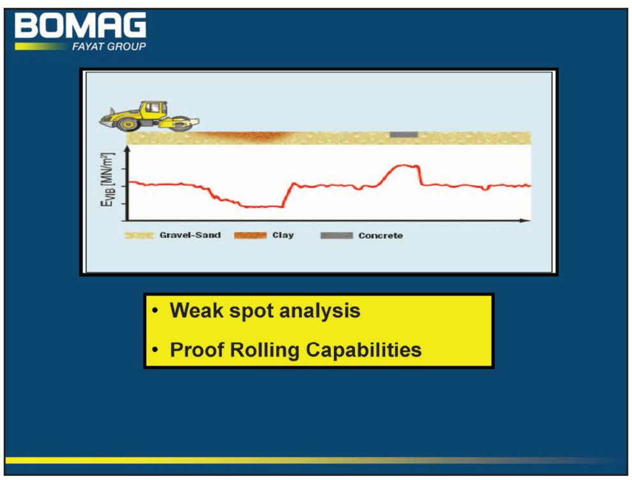

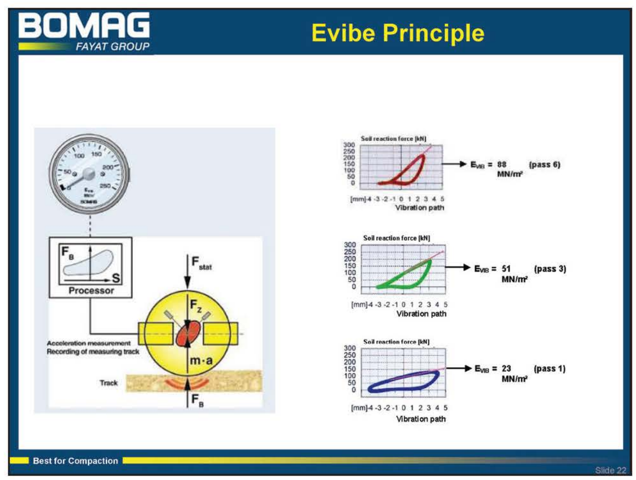

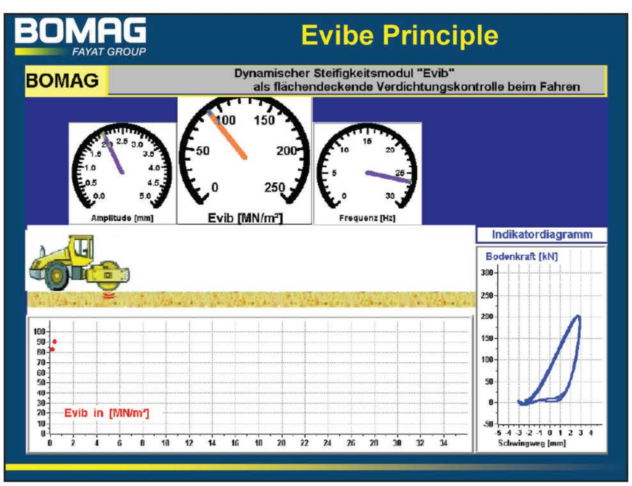

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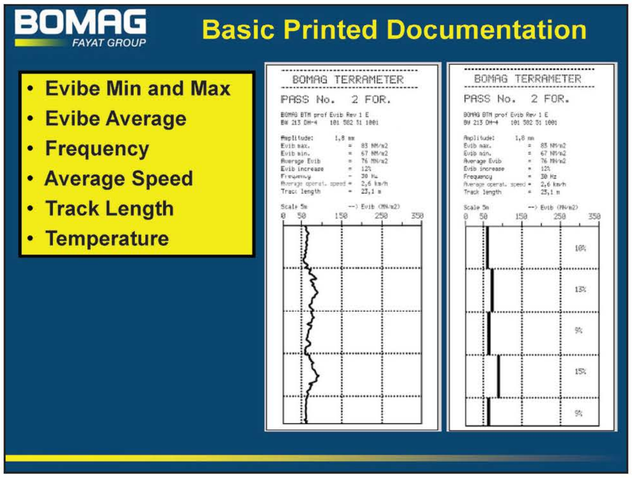

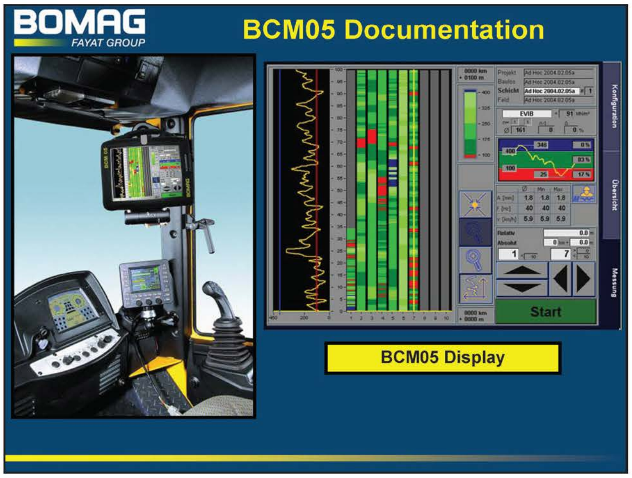

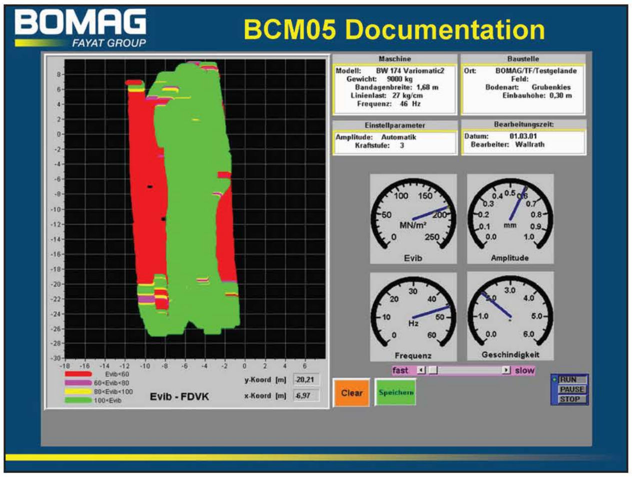

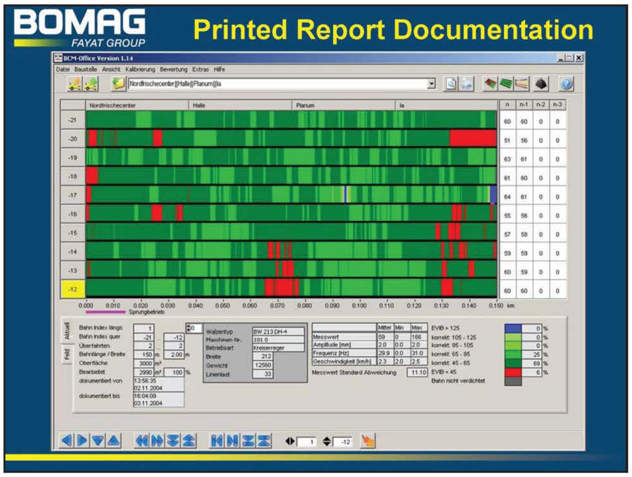

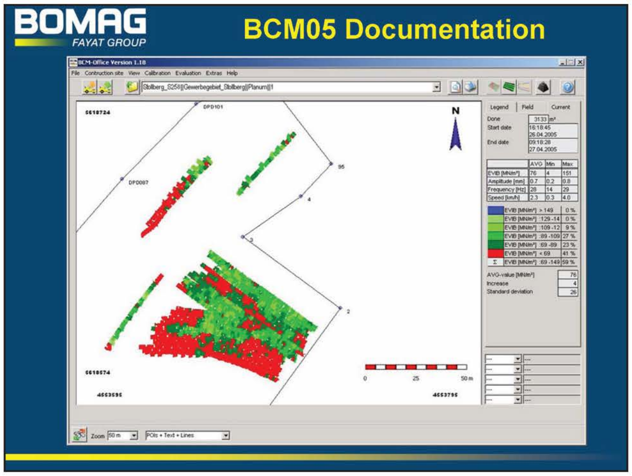

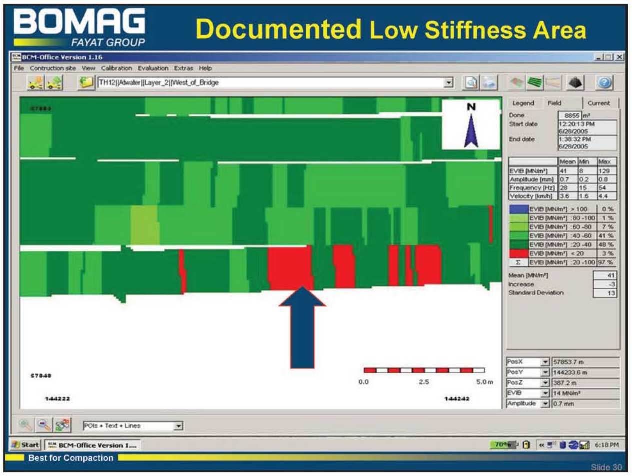

Overview of BOMAG IC Technology

Dave Dennison, BOMAG

Overview of BOMAG IC Technology

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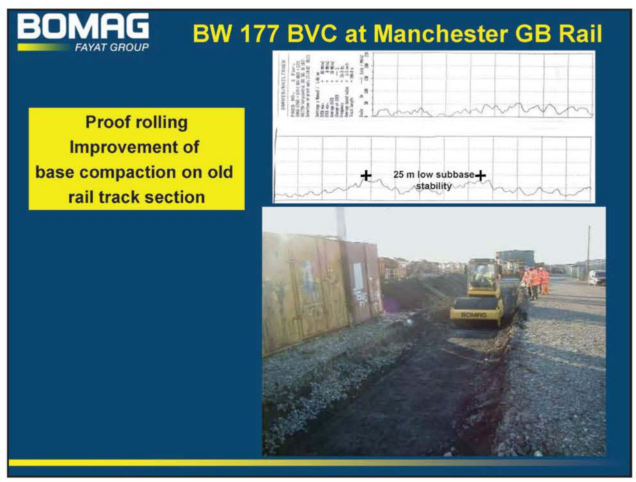

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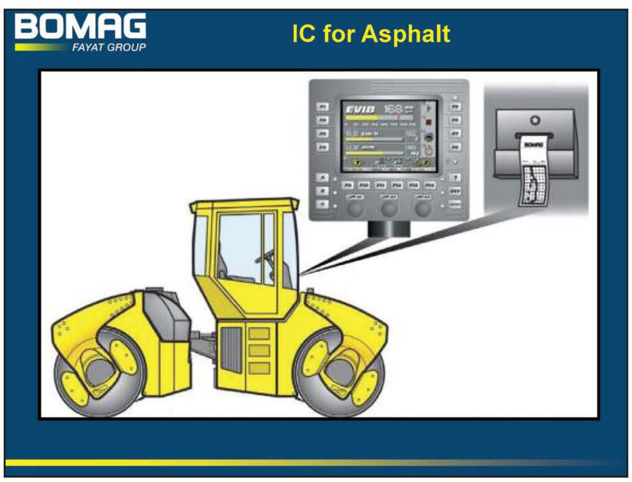
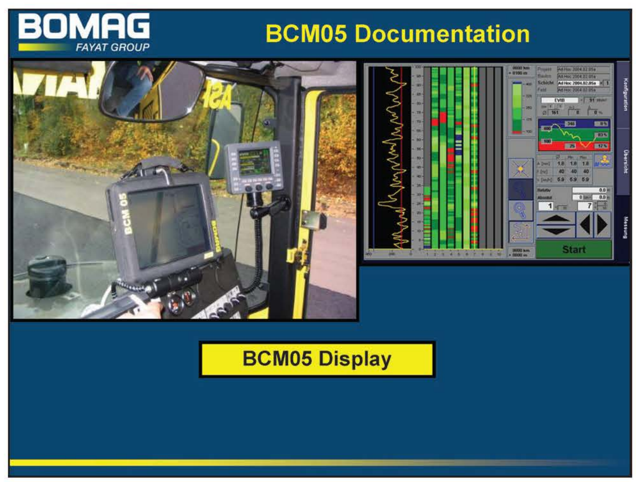
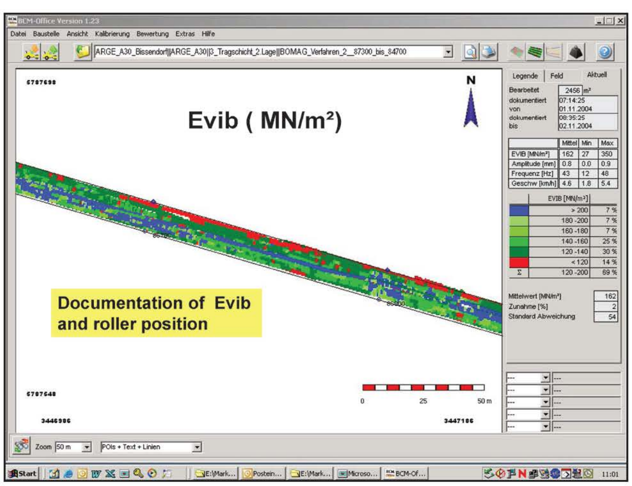
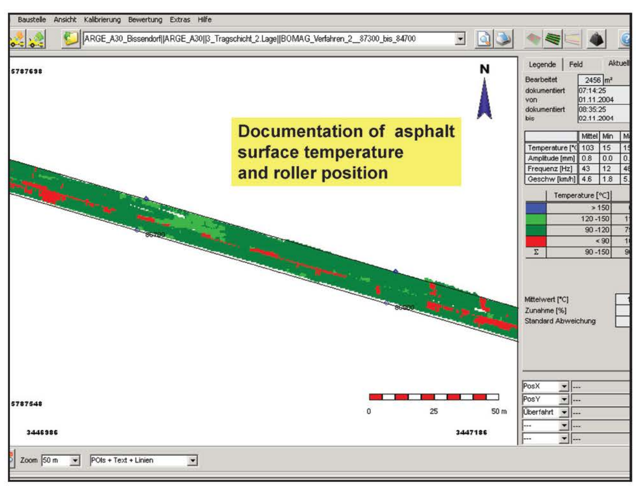


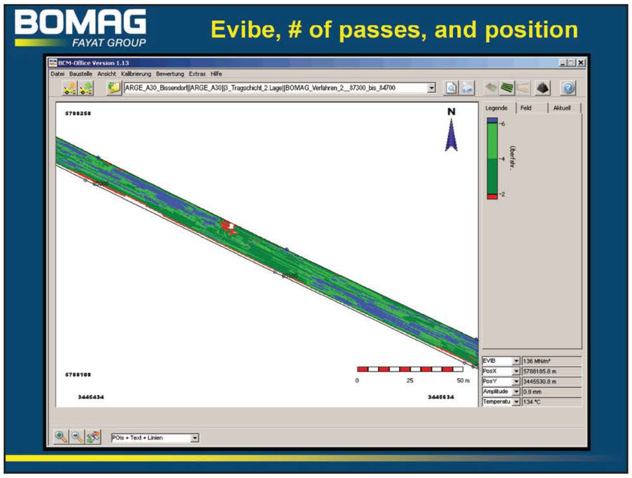


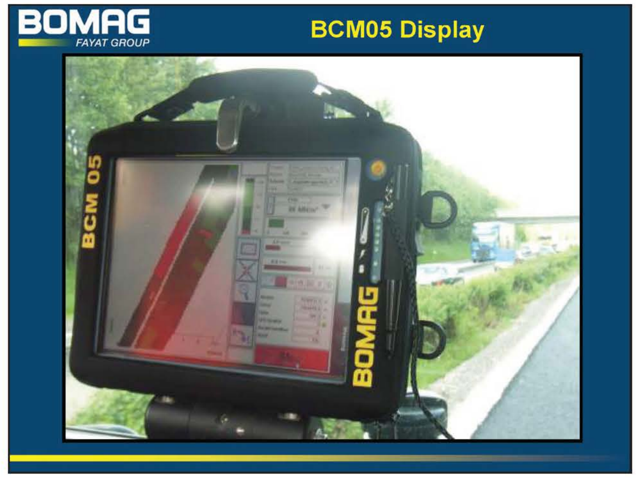


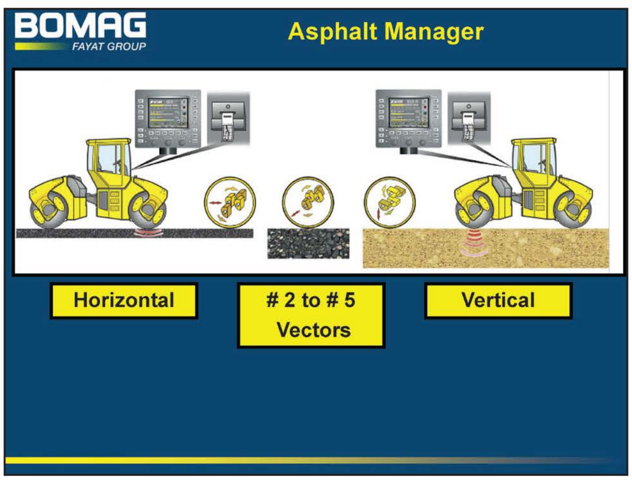


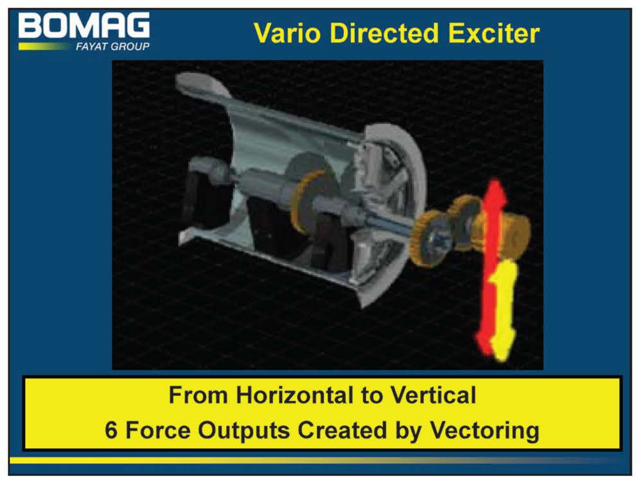
Overview of BOMAG IC Technology

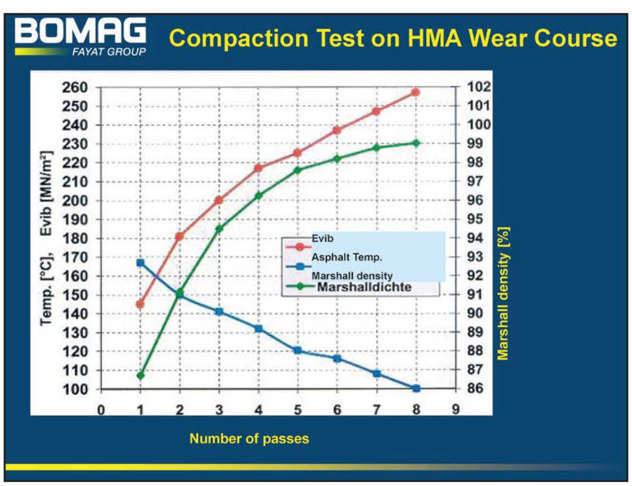
Dave Dennison, BOMAG

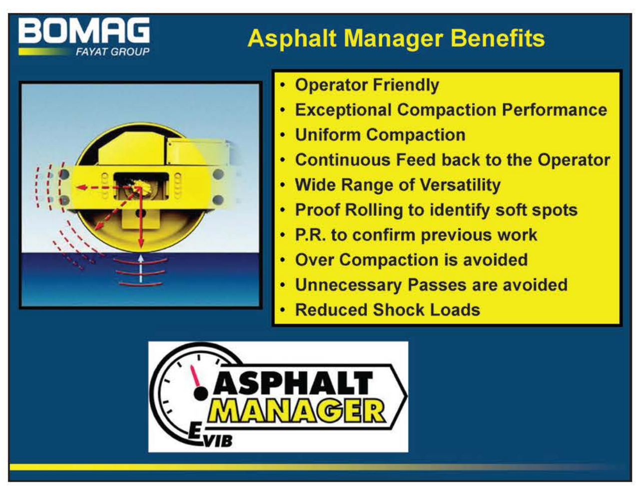






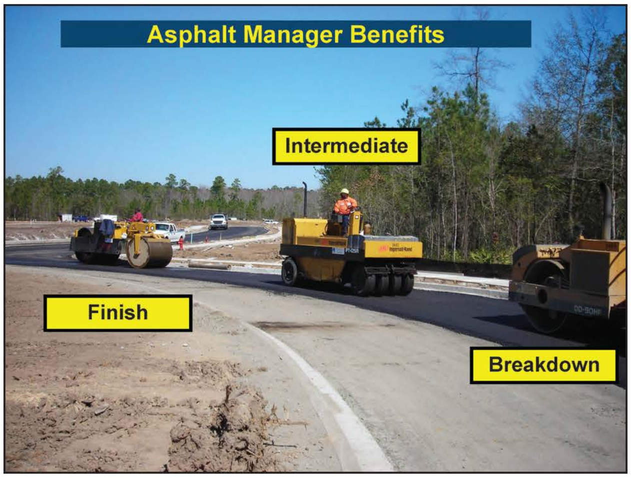






Overview of BOMAG IC Technology

Dave Dennison, BOMAG



Overview of BOMAG IC Technology

Dave Dennison, BOMAG


Connected Worksite Solutions
Terry Rasmussen, P.E.
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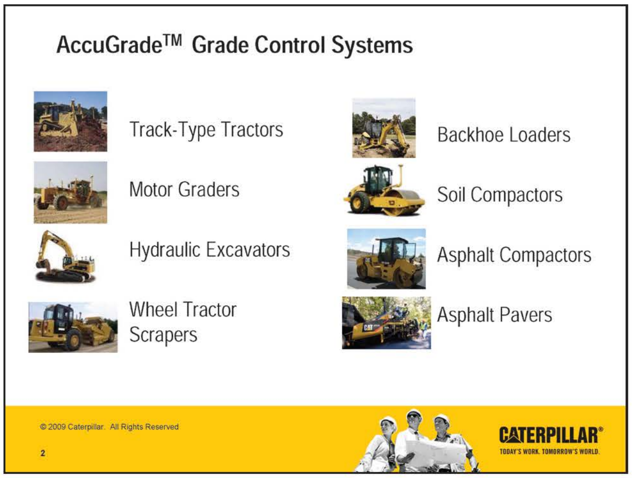
TODAY'S WORK. TOMORROW'S WORLD.


AccuGrade™ Grade Control Systems
Track-Type Tractors
Motor Graders
Hydraulic Excavators
Wheel Tractor Scrapers
Backhoe Loaders
Soil Compactors
Asphalt Compactors
Asphalt Pavers
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AccuGrade™ for Track-Type Tractors
Single & Dual Laser
Single & Dual GPS
Universal Tracking System (UTS)
Cab GPS
It is not just about fine grading…
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CATERPILLAR®
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Technology Enabled Road Construction
Controlled Study … Two Identical Roads … Same Crew
Conventional
AccuGrade
Step 1. Site Layout / Staking / Data Preparation
Step 2. Bulk Earthworks
Step 3. Sub Grading / Fine Grading / Grade Check
Step 4. Base Course Construction
Step 5. Base Course Grading / Fine Grading / Grade Check
Malaga
North Road: AccuGrade
South Road: Conventional
D6N
D6N AccuGrade GPS
330D
330D AccuGrade GPS
140H
140H AccuGrade ATS
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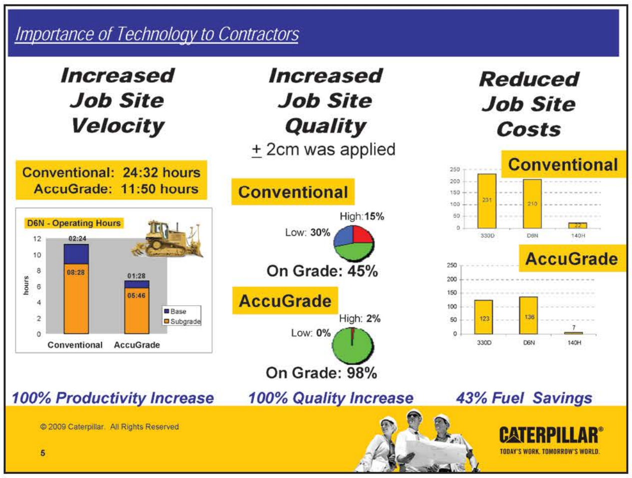
Importance of Technology to Contractors
Increased Job Site Velocity
Increased Job Site Quality
Reduced Job Site Costs
Conventional: 24:32 hours
AccuGrade: 11:50 hours
D6N - Operating Hours
Conventional
AccuGrade
Base
Subgrade
± 2cm was applied
Conventional
High: 15%
Low: 30%
On Grade: 45%
AccuGrade
High: 2%
Low: 0%
On Grade: 98%
Conventional
AccuGrade
330D
D6N
140H
100% Productivity Increase
100% Quality Increase
43% Fuel Savings
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5
CATERPILLAR®
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AccuGrade™ moving forward…
Integrating technology into machines
Position Sensing Cylinder (PSC) technology
With the PSC, the AccuGrade ® system is able to gather the current cylinder length and determine the current position of the bucket tip in real time (no visible sensor lag).
The PSC also removes the front linkage sensors from the traditional high wear areas such as the bucket linkage, and places them safely inside the bucket cylinder for increased integration, responsiveness, and reliability .
Position Sensing Cylinder
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Connected Worksite Solutions

Terry Rasmussen, Caterpillar

EquipmentManager

EquipmentManager is a web-based application that uses key indicators from your equipment such as hours, location and diagnostic codes and combines it with powerful tools like mapping, maintenance scheduling and troubleshooting instructions.

This application enables quick identification of actions required to maximize your equipment uptime and control owning and operating costs.

CATERPILLAR®
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Product Link

Product Link is the hardware that enables information flow between on-board systems and EquipmentManager using satellite technology.

Key indicators such as hours and location are delivered to EquipmentManager on a regularly scheduled basis. Other indicators such as diagnostic codes and unauthorized usage are launched from the machine by Product Link as they occur.

Product Link is offered as standard equipment on many Cat machines.

CATERPILLAR®
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Questions

Thank You!

Terry Rasmussen
309-494-6321
rasmussen_terry@cat.com

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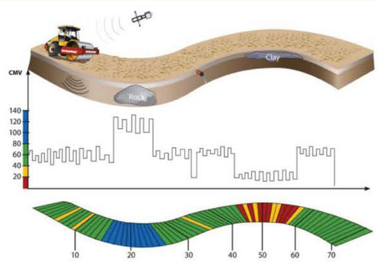
Dynapac Compaction Analyzer and Optimizer

Gert Hansson, DYNAPAC



Dynapac Compaction Analyzer and Optimizer

DYNAPAC
Part of the Atlas Copco Group

DYNAPAC
Part of the Atlas Copco Group

Dynapac Compaction Analyzer-Soil (DCA-S), Features

- Storage and analysis of compaction meter data
- Full-color 12,1" display for operator guidance
- Positioning
  - Relative
  - Absolute (GNSS) (Sub-meter to cm accuracy available)
    - With reference line or without
- Any local grid available
- Adjustable resolution
- Calibration module include
- Full analysis capability incl. TXT-file export
- PDF or paper print-outs
- Office and roller versions. Both include simulator mode

DYNAPAC
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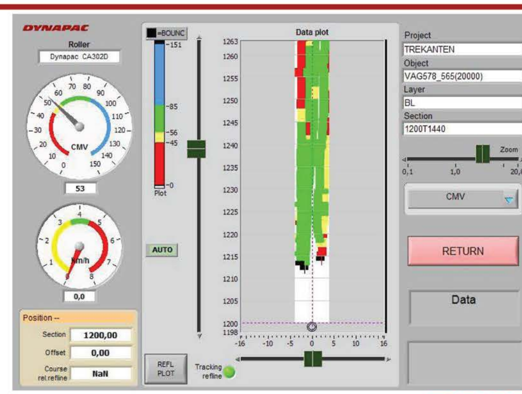
Production, station and offset



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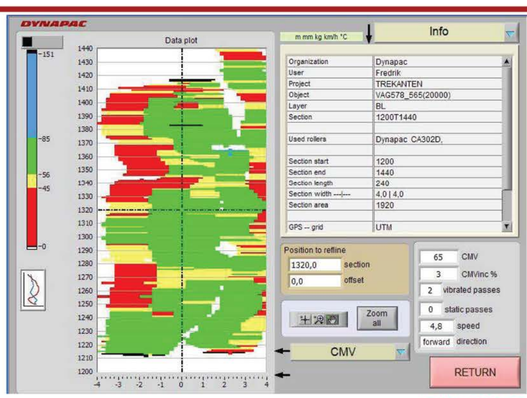
Analysis



Print-out

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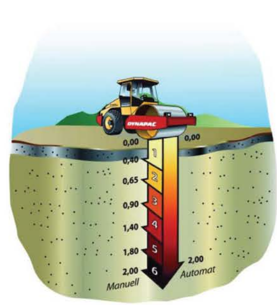
Dynapac Compaction Optimizer (DCO)



- Monitors the ground stiffness and adjusts the amplitude accordingly

DYNAPAC
Part of the Atlas Copco Group

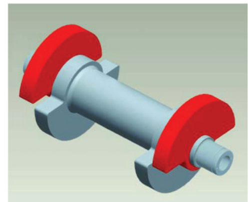
Dynapac Compaction Analyzer and Optimizer

Gert Hansson, DYNAPAC

Dynapac Compaction Optimizer-Features

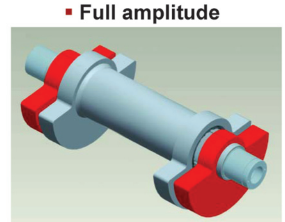
- 0-2 mm (0,079") amplitude
- Six manual steps or automatic, stepless adjustment
- Fully compatible with DCA

Eccentrics



- **Zero Amplitude**

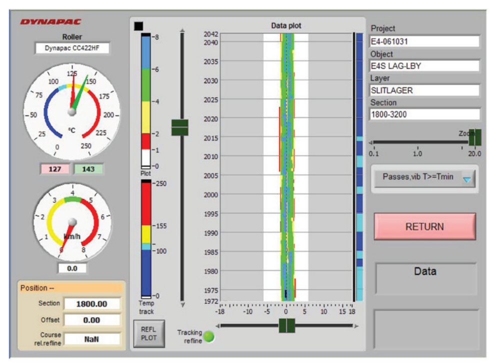
- **Full amplitude**



Dynapac Compaction Analyzer-Asphalt (DCA-A)

- Register the number of passes (static/vibratory)
- Measure and register the surface temperature (calculate core temperarure.)
- Graphic display of the temperature and the number of passes (real time in the roller)
- Documentation of the compaction process
- Background material for the quality analysis
- Support for continuous improvements of the paving process, rolling patterns and overall compaction results

Production mode-Roller screen



Workflow CompLogger

Analysis (office)
Transfer from CompLogger
-Print results
-Create PDF's
-Export text files
Save in compaction data archicve

Job site preparation (office)
-Decide on documentation setup
-Size of working areas
-Compaction target
Transfer to CompLogger

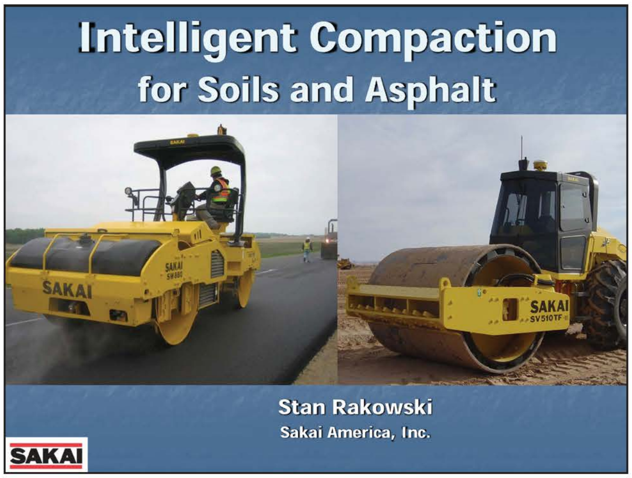
Production
-Collect compaction Data
-View graph or surface plot

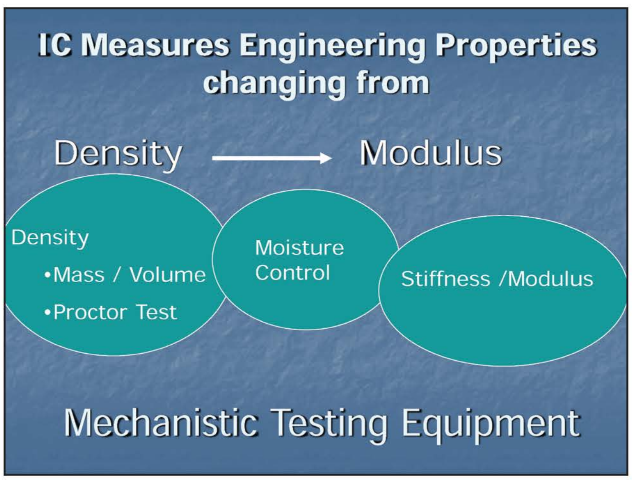
Benefits

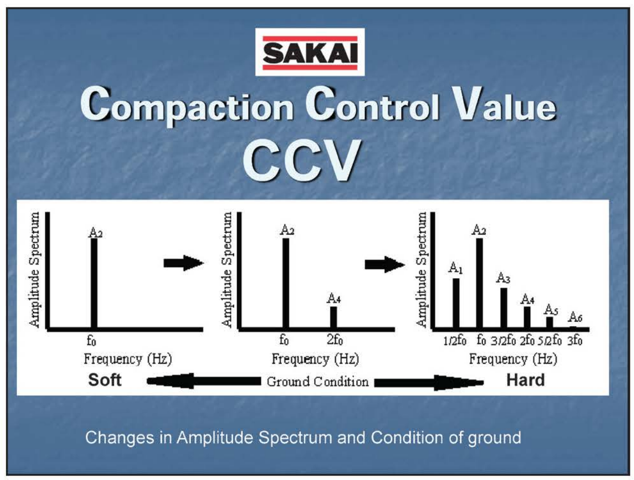
- Hand held, battery powered system
- Wireless communication
- Common interface with high-spec DCA
- Cost efficient CCC
- Huge leap from the competition in functionality and storage capacity.
- Full analysis and print function (B/W or Colour)
- Less than a five minute installation on any prepped roller.

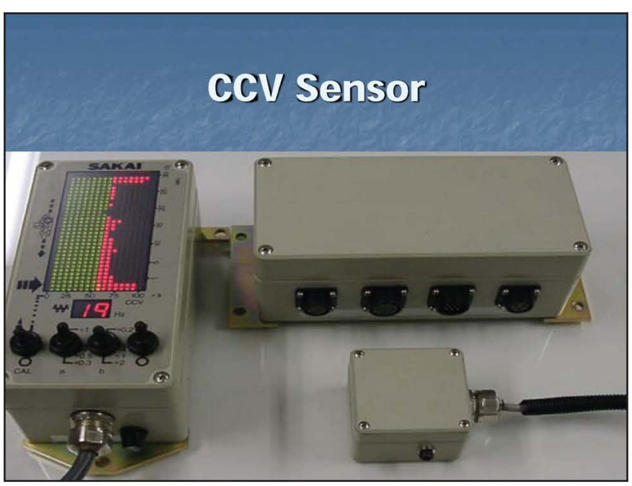
Intelligent Compaction for Soils and Asphalt

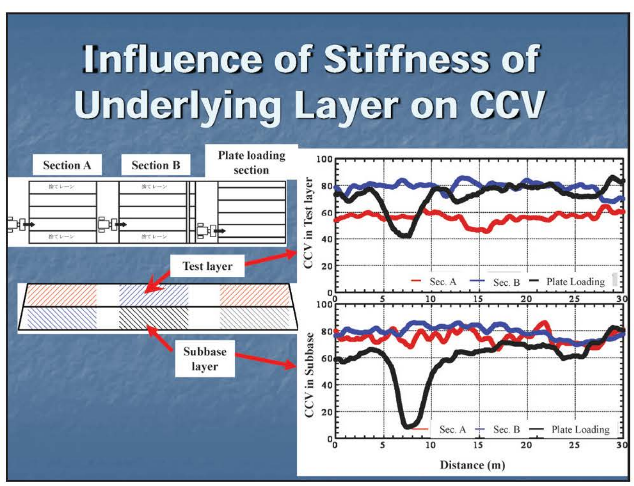
Stan Rakowski, Sakai





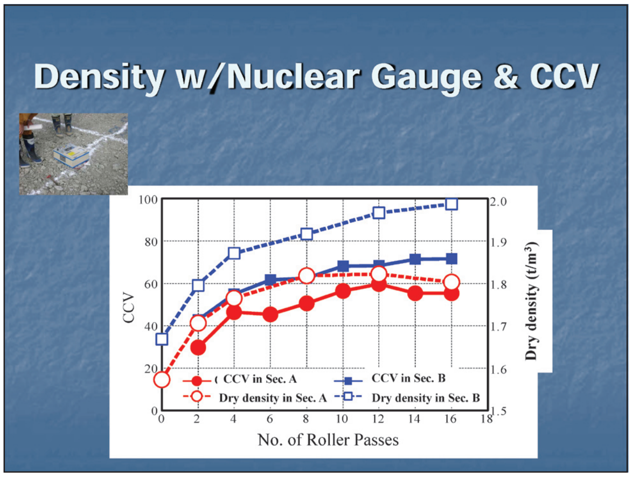


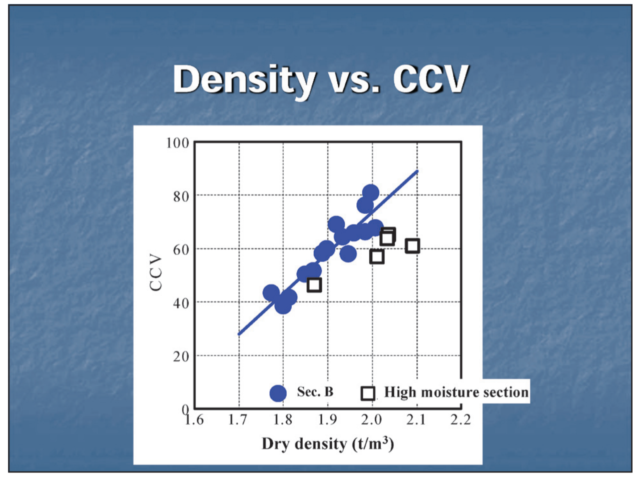


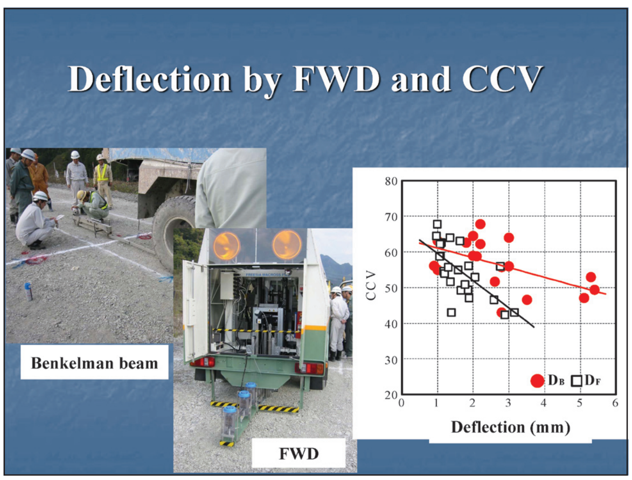


Intelligent Compaction for Soils and Asphalt

Stan Rakowski, Sakai

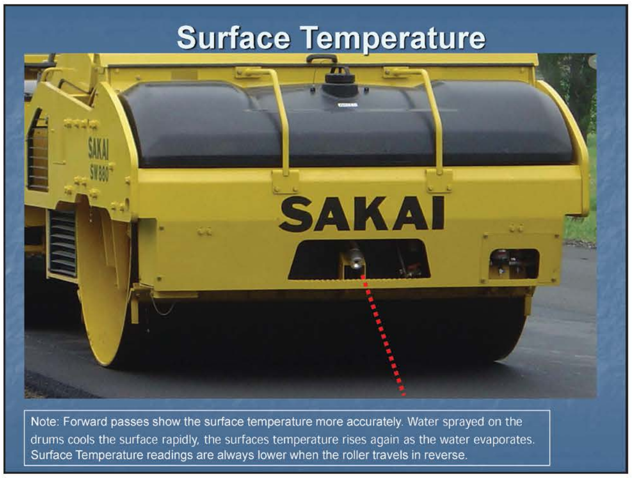


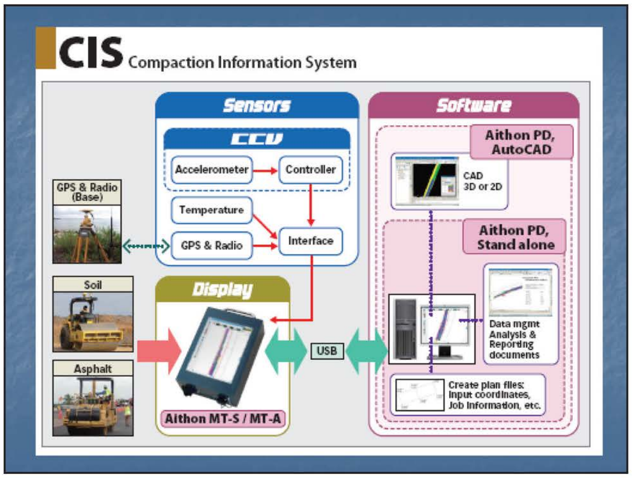


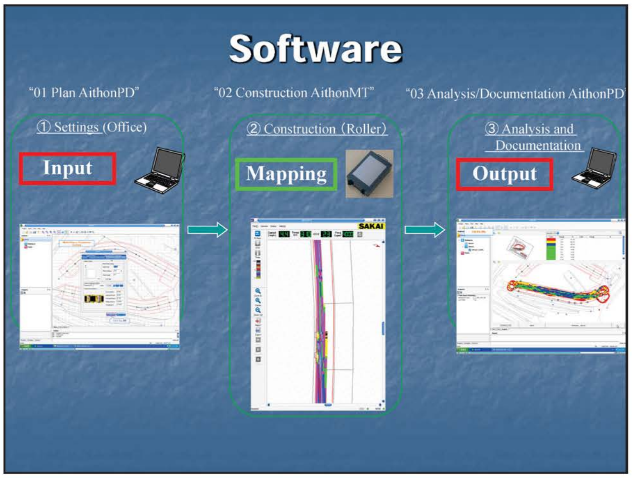


Intelligent Compaction for Soils and Asphalt

Stan Rakowski, Sakai

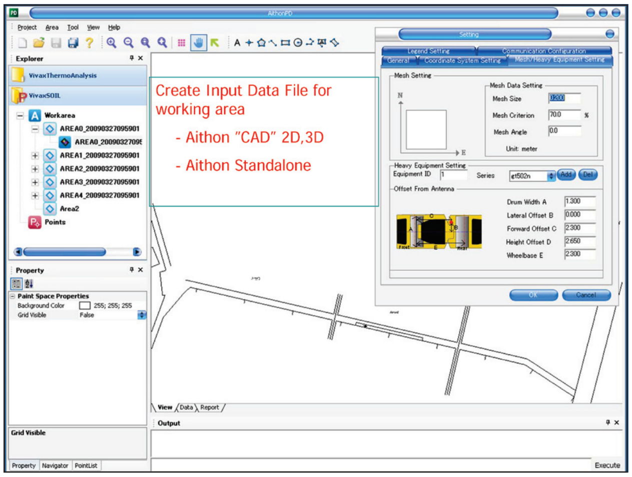


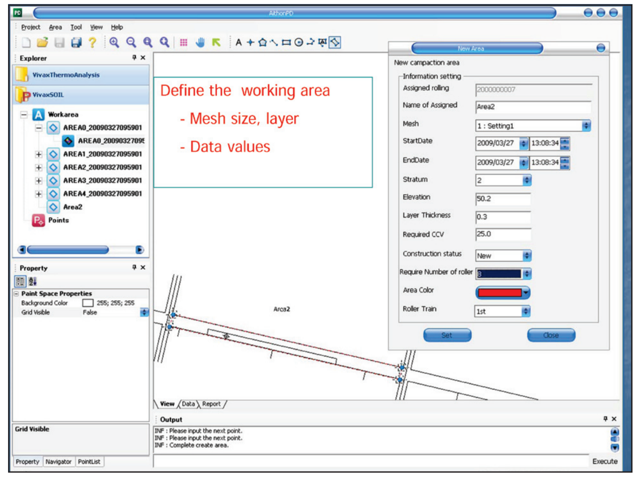


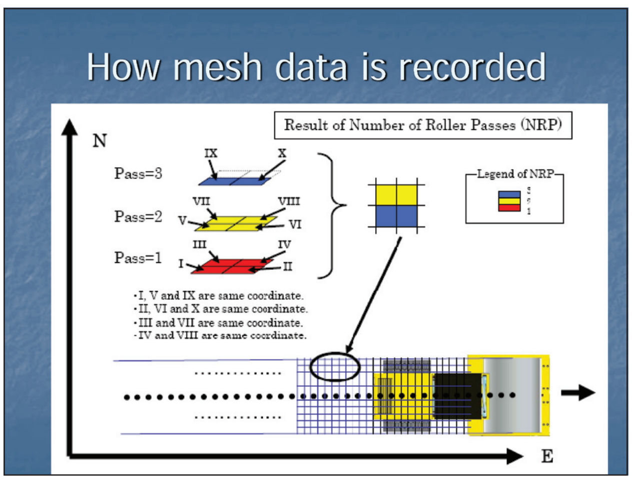


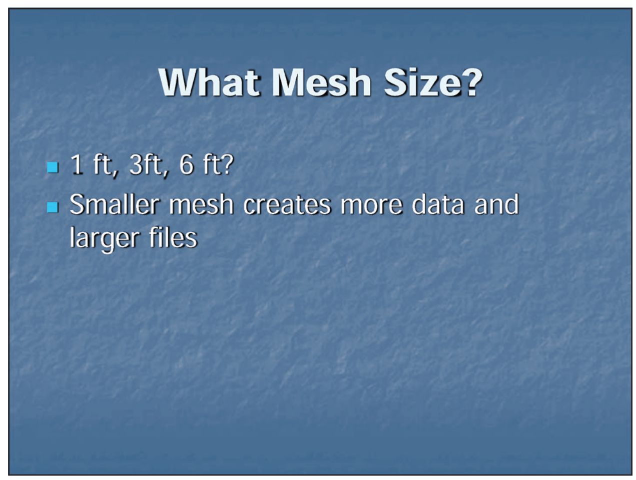
Intelligent Compaction for Soils and Asphalt

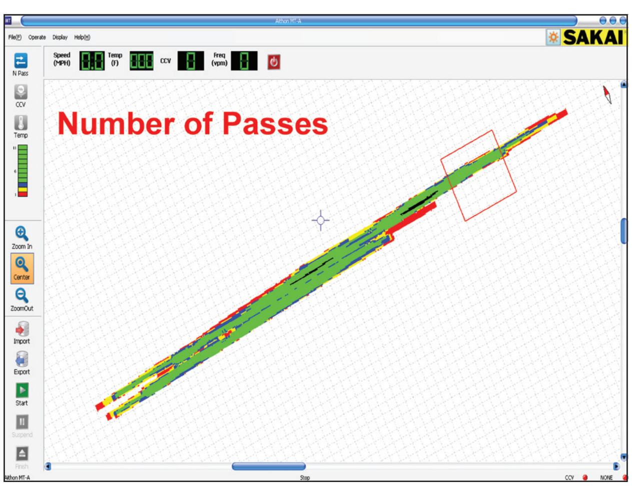
Stan Rakowski, Sakai

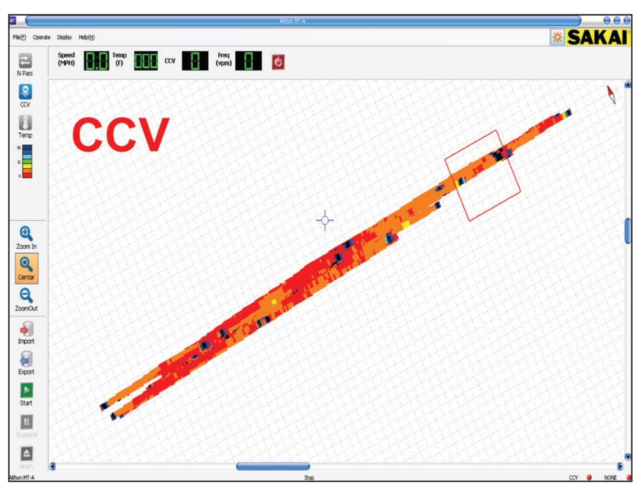












Intelligent Compaction for Soils and Asphalt

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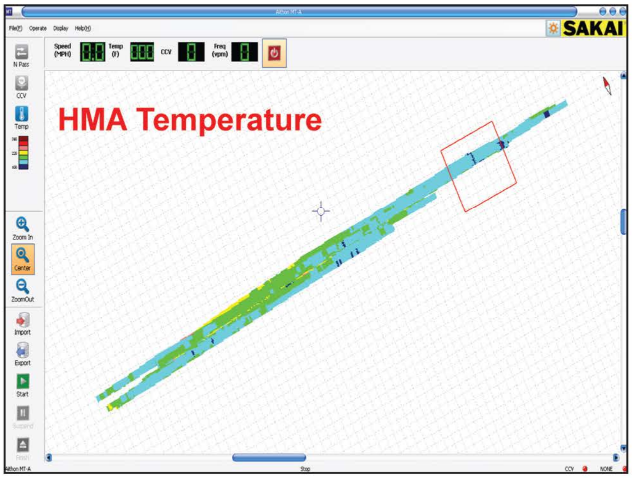
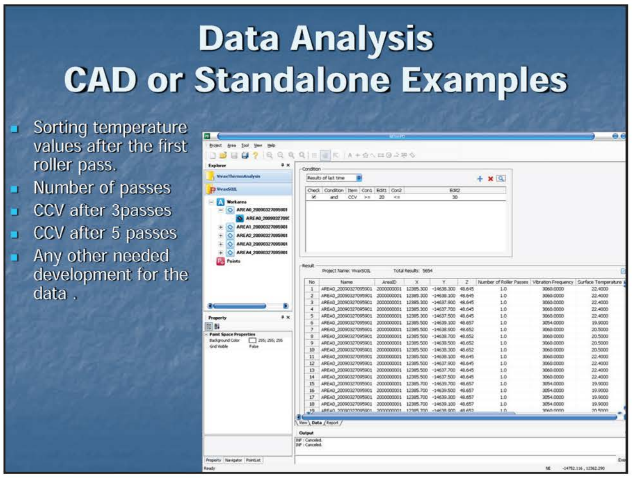
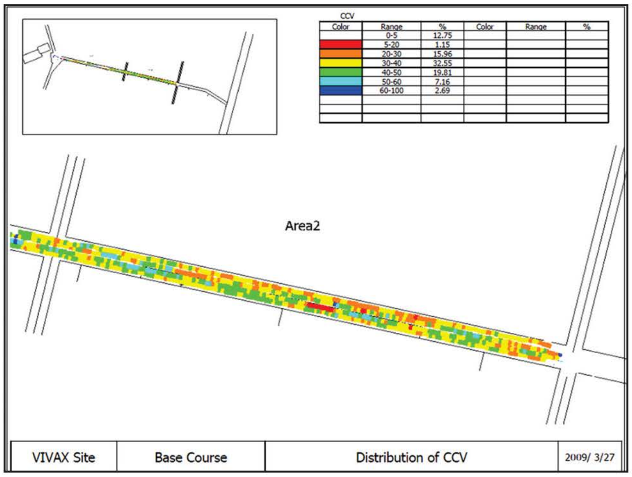
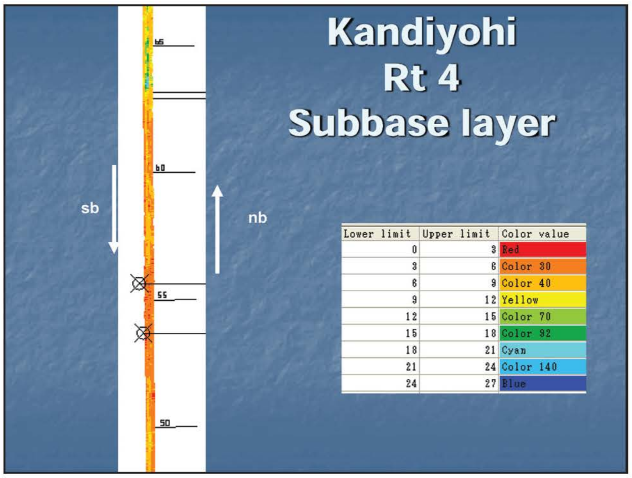






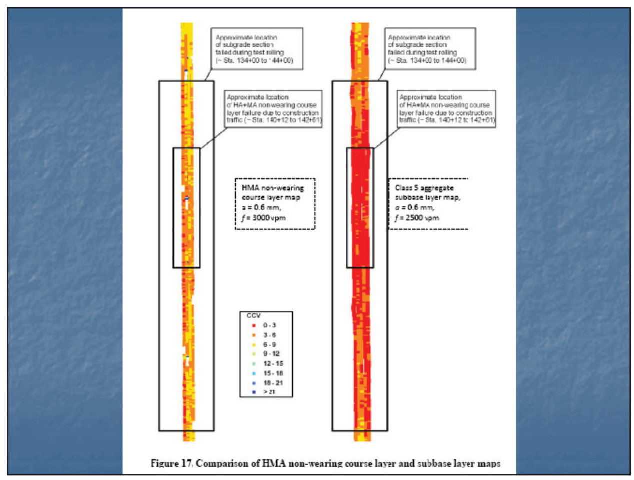
Color	Range	%	Color	Range	%
	0-5	12.75			
	5-20	1.15			
	20-30	15.96			
	30-40	32.55			
	40-50	19.81			
	50-60	7.16			
	60-100	2.69			

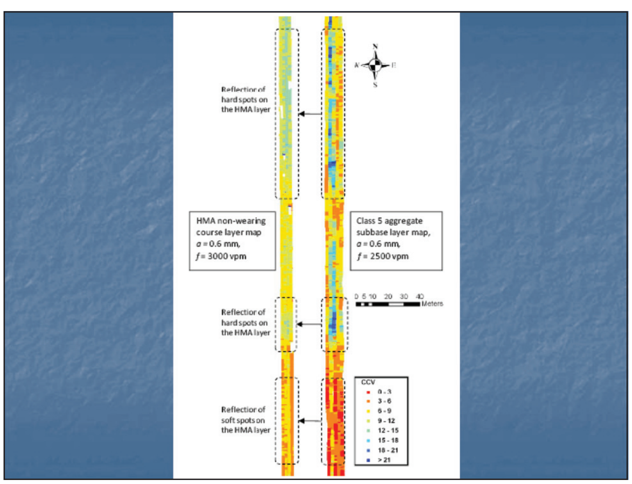


Lower limit	Upper limit	Color value
0	3	Red
3	6	Color 30
6	9	Color 40
9	12	Yellow
12	15	Color 70
15	18	Color 92
18	21	Cyan
21	24	Color 140
24	27	Blue

Intelligent Compaction for Soils and Asphalt

Stan Rakowski, Sakai





What we've seen so far?

- IC can improve QC/QA procedures
  - Data gives 100% roller coverage
  - Complete documentation for every lift
- Can quantify uniformity of compaction
- Data handling and analysis methods are improving
- Software is getting better and easier to use
- It works!

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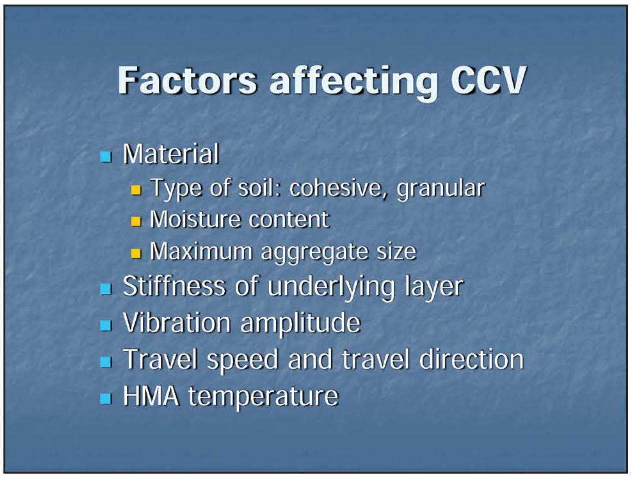
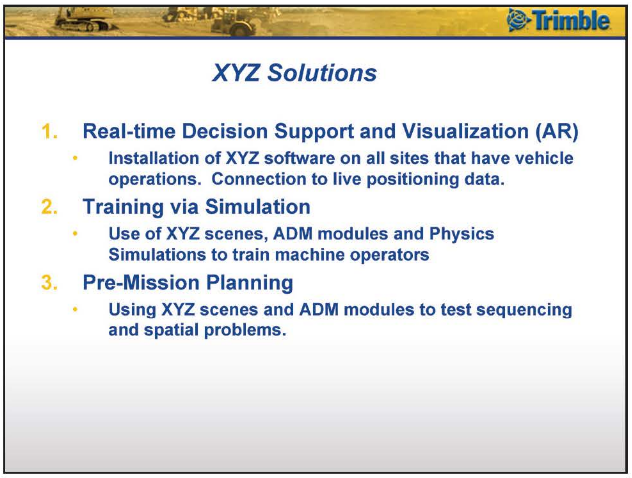

Factors affecting CCV
Material
Type of soil: cohesive, granular
Moisture content
Maximum aggregate size
Stiffness of underlying layer
Vibration amplitude
Travel speed and travel direction
HMA temperature

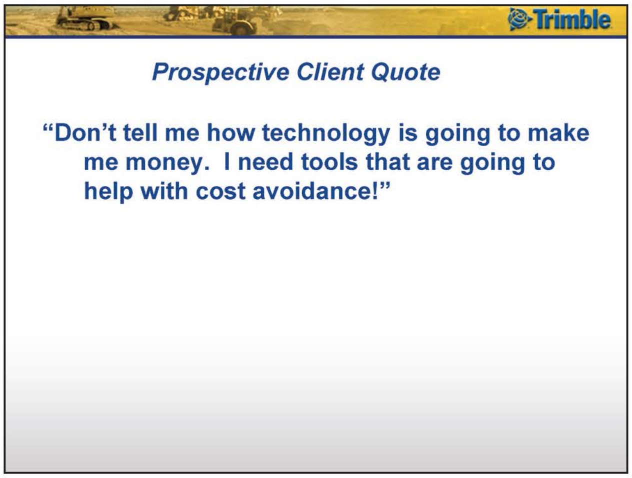

The Data
Speaks For Itself !


Thank You
SAKAI

Project Planning Using: GIS, GPS and RFID

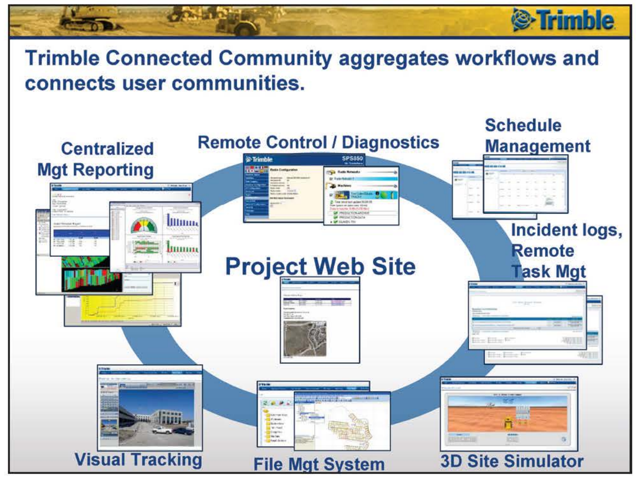
Kelly Miller, Trimble

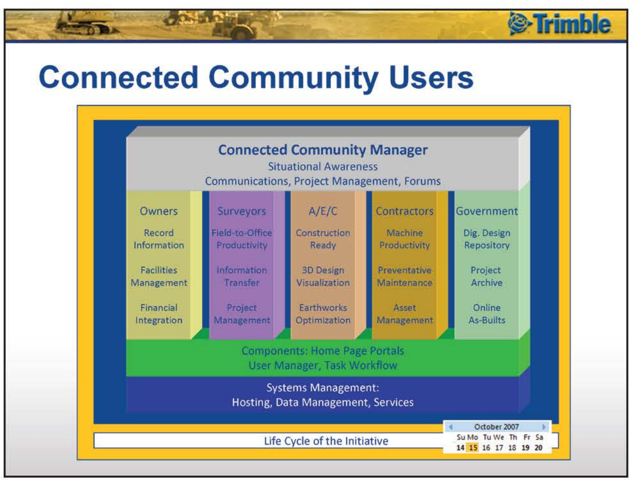


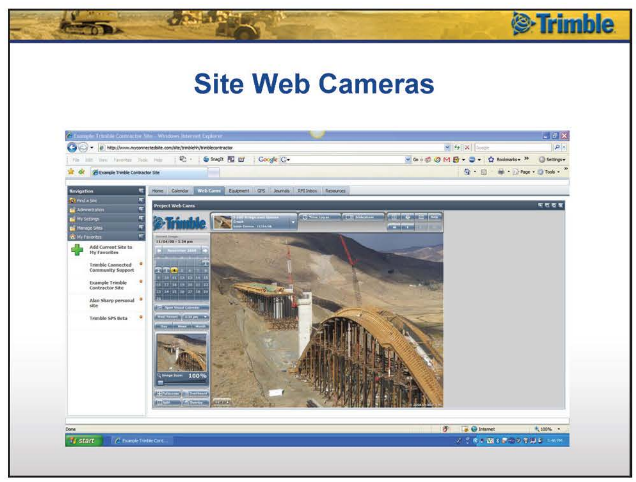


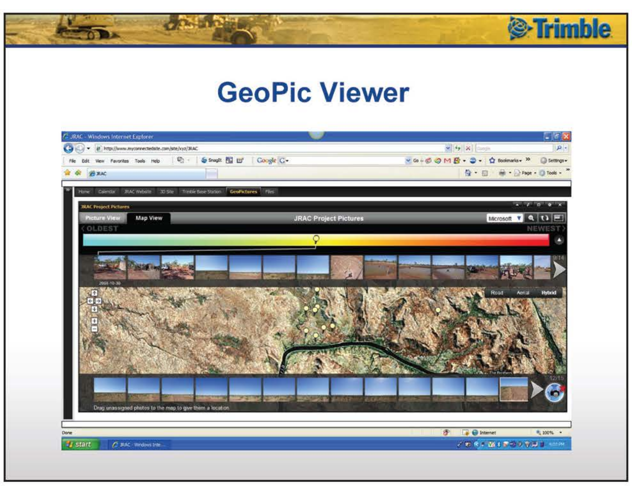
Project Planning Using: GIS, GPS and RFID

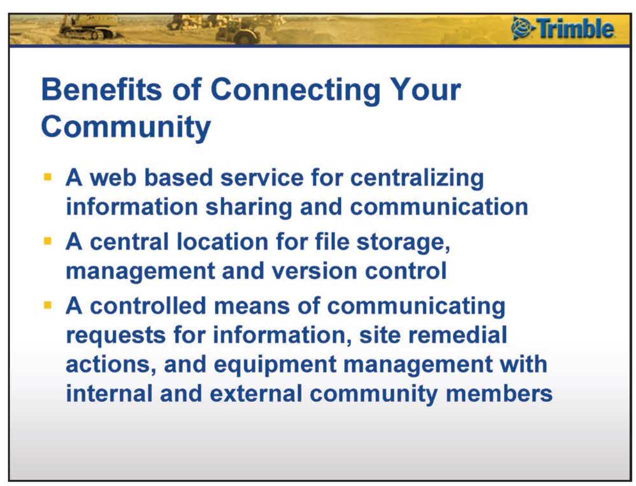
Kelly Miller, Trimble





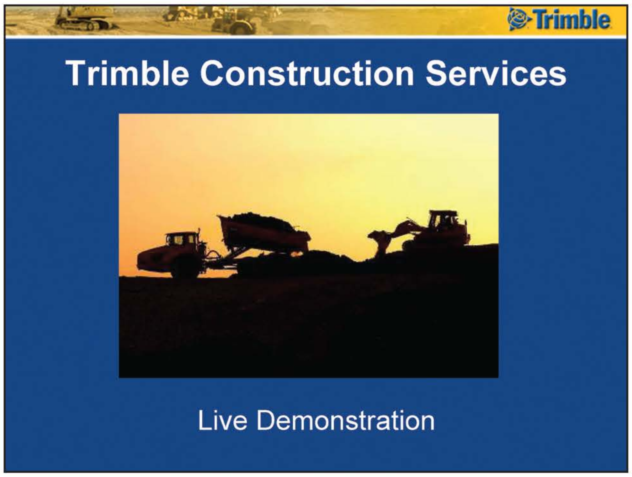






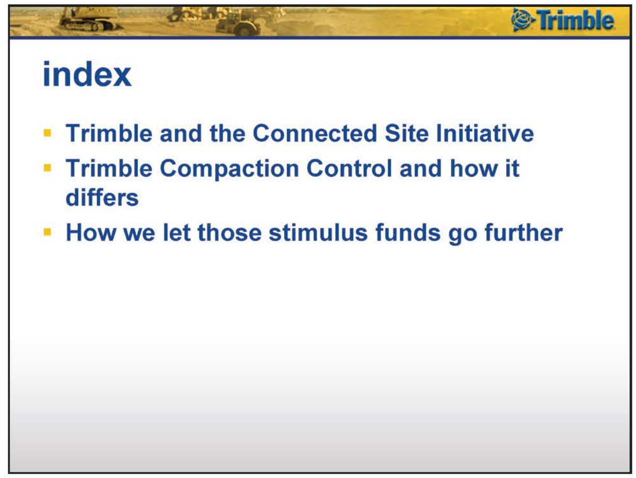
Project Planning Using: GIS, GPS and RFID

Kelly Miller, Trimble



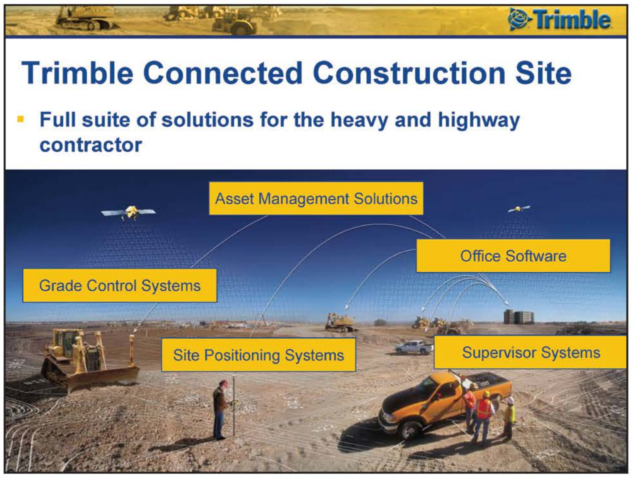
Trimble, Construction Technology and Compaction Control Systems

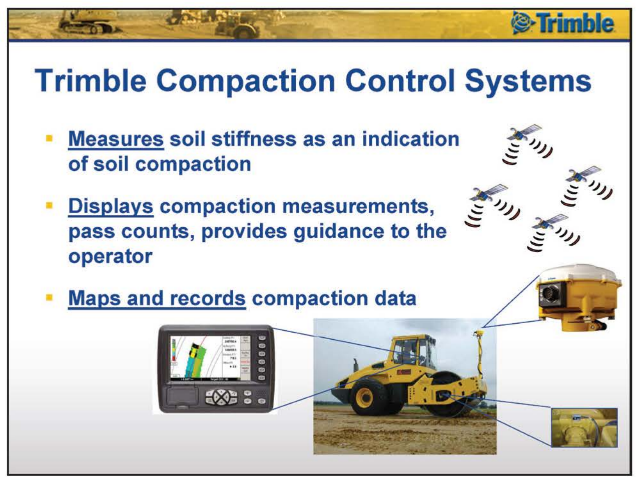
Jeroen Snoeck, Trimble

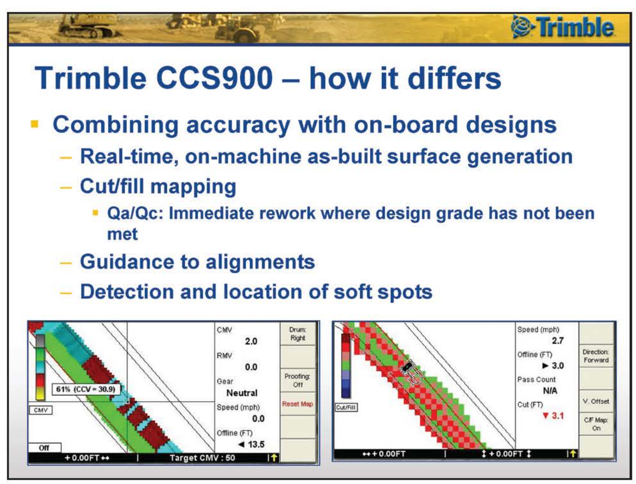


Trimble, Construction Technology and Compaction Control Systems

Jeroen Snoeck, Trimble

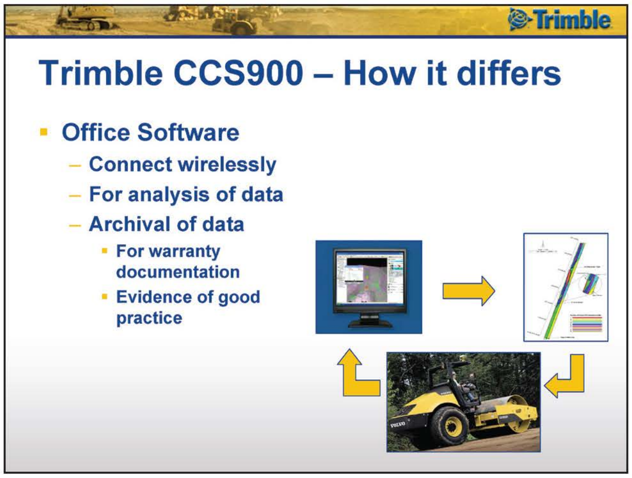


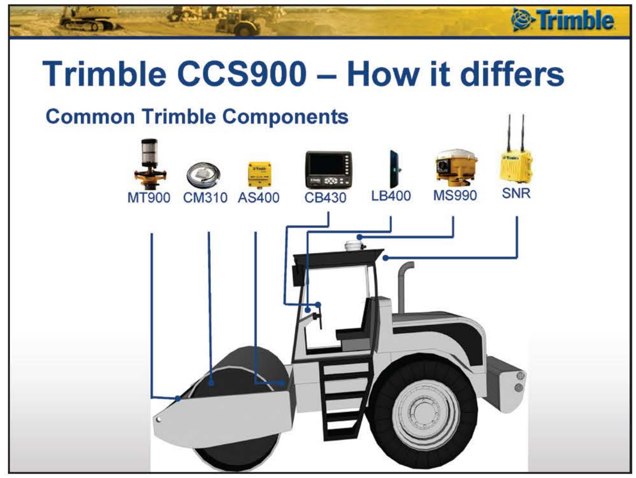


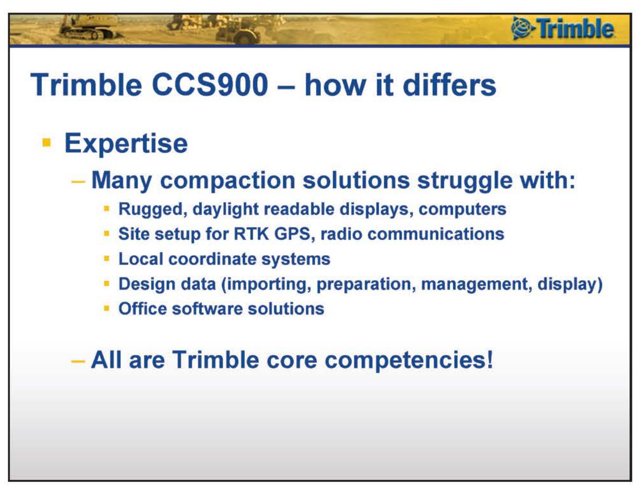


Trimble, Construction Technology and Compaction Control Systems

Jeroen Snoeck, Trimble







Trimble, Construction Technology and Compaction Control Systems

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Where we make a difference

- Combining accuracy with on-board designs
- Trimble Office Software - Compaction Module
- Common Trimble Components: Portability
- After market installation
- Trimble Connected Construction Site
- Expertise

Trimble

Let's take a step back

Let's take a step back

- Challenging economic times
- Stimulus funds for construction ~$40-60 Billion
  - Funded by us, the taxpayer
- How can we spend this money in a more efficient way?
  - Technology can help cut DOT and Contractor cost and increase product quality

Potential Value of Technology for States and Counties

- Construction process efficiency: Up to 80% reduction in rework, 70% reduction in machine time; 40+% reduction in fuel, 10% reduction in materials
- Speed: Finish 20-30% faster, reduced traffic and environmental impact
- Environmental impact: Up to 45% less fuel utilization on the site, on-road trucking reduction, less impact on existing road traffic
- End Product quality: More accurate and durable construction thanks to better information
- Safety: Keeping people out of trenches, away from machines, avoiding danger areas
- ….

The Technology is Mature

- The technology we are talking about has matured well beyond the initial experimental stage at which it was a decade ago and is really becoming mainstream
- Stories: http://www.trimble-productivity.com/

Summary

- Trimble broad technology range, expertise and system portability provide a unique offering in the compaction arena
- The GPS and 3D technologies are tried and tested and should be considered to cost construction costs and increase road quality

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Facilitator Report - Discussion

Tom Cackler, Ed Engle, Heath Gieselman, John Hannon, Charles Jahren, Pavana Vennapusa, David White, Paul Wiegand, Caleb Douglas

IOWA STATE UNIVERSITY
Civil, Construction & Environmental Engineering

Facilitator Report - Discussion

Intelligent Construction for Earthworks
West Des Moines, Iowa
April 14-16, 2009

Facilitators/Recorders: E. Tom Cackler, Ed Engle, Heath Gieselman, John J. Hannon, Charles Jahren, Pavana Vennapusa, David White, Paul Wiegand, Caleb Douglas

ctre Center for Transportation Research and Education
Iowa State University
EERC Earthworks Engineering Research Center

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

2009 Working Session Topic Areas

- **Topic #1** – Intelligent Compaction for Soils, Aggregate, and HMA – Review and Discuss the IC Roadmap and Develop Strategic Actions Plans
- **Topic #2** – Automated Machine Guidance – Discuss existing knowledge gaps? Equipment/software advancement needs? Educational/training needs? Specifications/standards?
- **Topic #3** – Intelligent Compaction Specifications and Performance-Based Specifications – Review and discuss outline for IC development specification and performance-based specifications for geotechnical/earthworks.

Topic #1 – Intelligent Compaction for Soils, Aggregate, and HMA – Review and Discuss the IC Roadmap and Develop Strategic Actions Plans

Breakout Session Discussion

1. Intelligent Compaction Research Database
   – Standardize storage and documentation
   – Database components: Design, construction, and long-term performance
   – Establish a public domain for data access
2. Intelligent Compaction and In-Situ Correlation Studies
   – Correlation studies on HMA and WMA
   – Relationships with density and stiffness (which is appropriate?)
   – Correlations with different in-situ test devices with different machine operation settings
   – Rapid determination of IC target values
3. Project Scale Demonstration Case Histories
   – Capture barriers to address during implementation
   – Compare IC results with conventional operations

Breakout Session Discussion

4. Intelligent Compaction Specifications
   – Data communication between contractor and owner
   – Reporting problematic areas
   – Standardized data format
   – Differentiate owner (e.g. QA) and contractor (e.g. QC) responsibilities
   – Separate specifications for Soils/Aggregate and HMA
   – Recommendations on roller operating parameters
   – Acceptance requirements (e.g., non-uniformity) depending on the compaction layer depth below the surface layer
   – Calibration standards for machines using independent measurements
   – Repeatability and accuracy of GPS and machine values
   – Incentive based pay factors to contractor
   – Consistency in measurement output units
   – Identify the state-of-the practice

Breakout Session Discussion

5. Educational /Certification Program
   – Contractor and agency certification/Training/Troubleshooting
6. Understanding Roller Measurement Influence Depth
   – Effect of different material types, geotextiles, cobbles, water table, foreign objects, utilities
7. IC technology Advancements and Innovations
8. In-situ Testing Advancements and Mechanistic based QC/QA
   – Rapid test procedures/device to replicate roller loading
   – Define mechanistic parameters to be used for QA
   – Critical engineering properties relative to the location of testing in an embankment

Facilitator Report - Discussion

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Breakout Session Discussion

9. Data Management and Analysis
   - Explore wireless data transfer capabilities
   - Explore effective ways for data storage
   - Continued research on geostatistical analysis for uniformity
   - Options for simple to robust analysis
   - What type of data resolution needed?
   - Criteria for data filtering
   - Extent of detail in the data to be retained

10. Understanding Impact of Non-Uniformity on Performance
   - How do you define uniformity? (variance, coefficient of variation)
   - What is acceptable and what is not?
   - What is the critical area in embankment where it should be uniform?
   - Effect of vertical and spatial non-uniformity on performance

Prioritized IC Road Map Elements

1. IC Specifications (41)
2. IC and In-Situ Correlation Studies (25)
3. In-Situ Testing Advancements and Mechanistic Based QC/QA (20)
4. Understanding Impact of Non-Uniformity on Performance (16)
5. Data Management and Analysis (16)
6. Project Scale Demonstration Case Histories (13)
7. Understanding the Measurement Influence Depth(13)
8. IC Technology Advancements and Innovations (9)
9. IC Research Database (8)
10. Educational/Certification Program (8)

Topic #2 – Automated Machine Guidance – Discuss existing knowledge gaps? Equipment/software advancement needs? Educational/training needs? Specifications/standards?

Knowledge Gaps and Deficiencies

1. Lack of documented experience and champions (17)
2. Transition 2D to 3D design practice (11)
3. File compatibility issues (7)
4. Limited desire to move toward pavement AMG (stringline is "safe") (6)
5. Surface information and design changes should be left in the hand of the designer, not modified by the contractor (2)
6. Currently the paper document is the legal document, design files are often under a disclaimer for inaccuracy (2)

Education/Training

1. Initial training + experience + follow-up training (10)
2. Future conferences/workshops/web-based training (7)
3. Certification (2)
4. Use of intelligent design tools will increase efficiencies (2)

Specification/Standard

1. Acceptable tolerances linked to construction elements (rough grade, finish grade, paving, etc)(9)
2. Specification inclusive of various technologies (Laser, GPS, Total Station) (3)
3. Object referencing (e.g., top of curb vs. gutter flow line?) (1)
4. Design surface file size limitations (computer, software and AMG machine limits) (1)
5. When will the best utilization of resources be obtained using AMG and 3D design? (1)
6. When are specification and design files available to contractor? (1)
7. Solicit wide ranging review/feedback (1)

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Topic #3 – Intelligent Compaction Specifications and Performance-Based Specifications – Review and discuss outline for IC development specification and performance-based specifications for geotechnical/earthworks.

Goals

- Develop a specification that is not technology specific
- Define what DOT's want to measure and format of the data

Specification Options Review

- Option 1: Roller based QC with pre-selected MV-TVs
- Option 2: IC-MV maps to target locations for QA point measurements
- Option 3: MV-TVs from compaction curves to target locations for QA point measurements
- Option 4: Calibration of IC-MVs to QA point measurements
- Option 5: Performance based QA specification with incentive based payment

Key Attributes of IC Specification

1. Descriptions of the rollers and configurations, GPS (accuracy), other position technology?
2. Guidelines for roller operations (speed, vibration frequency, vibration amplitude, and track overlap) (normalization),
3. 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)
4. Repeatability and reproducibility measurements for IC measurement values (IC-MVs),
5. Ground conditions (smoothness, levelness, isolated soft/wet spots/high GWT, variation of materials)
6. Calibration procedures for rollers and selection of calibration areas (variable soils), (independent site/mechanical, see superpave)
7. Simple linear regression analysis (statistical analysis, populations?) between IC-MVs and point measurements (moisture content) (stiffness),
8. Number and location of quality control (QC – what testing for w%, DD?) and quality assurance (QA- what testing/independent) tests,
9. Operator training, and (certification)
10. Basis of payment/incentives
11. 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)

Identified 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
- DOT's need to agree upon what end result properties they want to measure – "gold standard"
- Soils and asphalt will need separate specs.
- IC use for QA requires FHWA verification
- What is the IC tool for the state agency?

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

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Next Steps

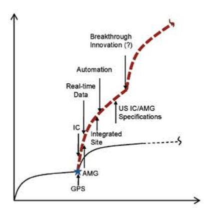
- Education – Identify benefits
- Technology transfer involving manufacturers, contractors, and state DOTs
- High quality DVD
- Develop standalone tools/software for inspector
- Develop consensus approach for specification

Action Items

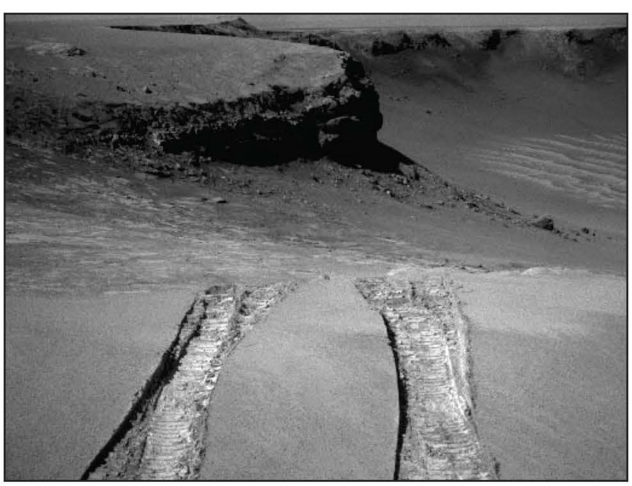
Action Items

- 6 Case Histories (Tech Briefs)
- 6 Webinars
- Specifications Technical Working Group (TWG)
- EERC Website

- Explore NHI Course
- Research Gaps
  - Develop Problem Statements
  - Identify Key Research Partners



- AASHTO Technology Implementation Group
  - Proposals submitted annually
  - Involve many state DOTs



State DOT Briefings

In a one-hour session on day 1, state DOT representatives from WI, KY, MI, VA, NY, SD, IL, MO, MS, KS, TX, GA, LA, and WA provided a brief summary of their current state of practice and research involvement relating to AMG, IC, and in situ QA/QC. Excerpts from this session are as follows:

Wisconsin Department of Transportation (WisDOT)

- Recently started implementing AMG on earthwork projects using special provisions to contracts. WisDOT provides a Microstation model to the contractor, and then contractor develops a 3D model and cross-checks with WisDOT before using it on the project. WisDOT does periodic spot-checking.
- A new IC research project started in coordination with ARA, Inc., and University of Wisconsin. Project scope includes investigating three types of soil, aggregate, and asphalt materials using three types of IC rollers. Project starts during summer 2009.

Kentucky Transportation Cabinet (KYTC)

- Have been allowing AMG on earthworks the past several years and is included in current specifications. KYTC performs QA using periodic conventional spot-checking. KYTC gives the contractor a Microstation file and contractor generates 3D model. Currently, five contractors in the state use AMG on earthwork projects. Six of twelve districts in the state now have GPS/Total Station equipment for spot-checking.
- Collaborating with University of Kentucky to figure out how to implement IC for Kentucky soils. Soils are variable from large rock/boulder fill to cohesive soils. Have been trying LWD on cohesive soil projects. Limitedly used DCP on cohesive soil projects. Interested in moving away from nuclear gauge testing.

Michigan Department of Transportation (MDOT)

- Not done anything yet on IC.
- Interested in using alternative QA/QC methods to nuclear gauge testing. No research was performed on this aspect yet.
- Two projects were conducted using AMG in 1997 and 1998.

Virginia Department of Transportation (VDOT)

- Not done anything yet with IC on soils. Conducted couple of research projects on HMA using IC, however results were inconclusive.
- Certainly interested and willing to pursue to better understand IC equipment and to understand what the output numbers mean. Interested in correlations with non-nuclear methods for QA.
- Information from IC rollers such as location of roller and number of passes is very helpful to document. Need to understand/study more to use stiffness measurements from roller.

New York State Department of Transportation (NYSDOT)

- Participant of FHWA IC pooled fund study. A demonstration project is scheduled for this summer on US 219 in Springville, NY. Project involves testing on granular subgrade and subbase materials using Bomag and Caterpillar single smooth drum IC rollers.
- Recently started investigating the use of Zorn LWD, TransTech's Soil Density Gauge (non-nuclear), and Electronic Density Gauge devices for QA/QC.
- Use of AMG is contractor driven. No requirement by NYSDOT. No new specifications planned yet.

South Dakota Department of Transportation (SD DOT)

- Not done anything yet on IC. Interested in pursuing research with granular embankment materials and granular fill with MSE walls.
- Tried using Soil Stiffness Gauge – results were inconclusive as the soils were too coarse.
- Concern – half of the state is covered with highly expansive soils with need of high moisture contents (close to optimum) during compaction. Will stiffness be good enough to check quality?

Illinois Department of Transportation (IDOT)

- AMG has been likely used recently on some earthwork projects.
- Currently use nuclear gauge for QA/QC on soils and HMA. Interested in more research with IC. Currently, no demand in state to eliminate nuclear gauges. Also use DCP for subgrades and foundations and static cone penetrometer in problematic subgrades.

Missouri Department of Transportation (MoDOT)

- No projects with AMG.
- Will be using IC on HMA this summer. Willing to move away from using nuclear gauges. Limitedly used DCP. Did a research project with ISU (Dr. Chris Williams) on permeability testing on HMA instead of nuclear density testing.

Mississippi Department of Transportation (MDOT)

- Participant of FHWA IC pooled fund study. A project in southeast Mississippi with cement-stabilized soils has been identified for IC demonstration project.
- Contractor and state DOT personnel quite interested in understanding more about IC.

Kansas Department of Transportation (KDOT)

- Participant of FHWA IC pooled fund study. Did a project last August as part of the pooled fund study. Waiting to see research results before pushing for implementation.
- No push on AMG yet.

Texas Department of Transportation (TxDOT)

- FHWA IC pooled fund participant—did a project last year. Results are encouraging.
- Planned another project for August 2009 on soil and base materials. At this stage, IC will not be used for QA but will be used for QC. Waiting for example specifications from other states.

Georgia Department of Transportation (GDOT)

- All the IC work has been only on HMA. Conducted two demo projects in spring 2008 using Sakai and Bomag IC rollers on HMA. Contractors on the projects were very interested in trying the new technology. The projects were several miles long, so had to move base stations time to time to get readings. Nuclear density gauge and density cores were taken for comparison at random locations. Correlations between density and IC stiffness values on one project were not good while on other project were good. Roller pass coverage information was helpful—results showed that contractor did not achieve consistent roller pattern.
- FHWA pooled fund study participant. A demo project is planned on a parking lot as part of the pooled fund study—will map stiffness of base before paving to compare results with HMA layer stiffness.
- Willing to learn more about IC on soils.
- Successfully implemented AMG on two pilot projects. These projects were initiated on contractor's request. Developed special provisions to allow for AMG.

Louisiana Department of Transportation and Development (LA DOTD)

- No studies on IC yet.
- Interested in using IC to address QC issues on soils and HMA. Having questions about which methods are best for QA, how can moisture be measured by rollers in soils, and how does the electronics in the machines work.

Washington State Department of Transportation (WSDOT)

- Not done anything on IC yet.
- Currently use nuclear gauges for HMA and soils. Tried some electrical density gauges—not certain on its benefits yet.
- AMG—not certain on its use in the state.

Iowa Department of Transportation (Iowa DOT)

- Developing an IC research project in collaboration with ISU. Looking at three construction projects this year with limited testing and will be conducting more rigorous testing next year.

Breakout Sessions

On day 2, six breakout sessions were conducted covering three topic areas listed below. Each topic area had a morning and an afternoon session. A sign-up sheet was provided on day 1 to target about 20 participants per each group session. Each group had a facilitator and a recorder. The brief agenda used for discussion in the breakout sessions is provided under each topic.

- **Topic #1: Intelligent Compaction for Soils, Aggregate, and HMA—Review and Discuss the IC Roadmap and Develop Strategic Actions Plans**
    - Review the road map/top 10 technology and research need identified in the 2008 workshop report.
    - Discuss and debate each topic area.
    - Develop an updated road map and rank the topic areas using participant voting.
    - Identify action plans, leadership roles, and potential funding needed to move forward on each topic.
    - Develop a schedule on the duration of the proposed action plan.
- **Topic #2: Automated Machine Guidance—Discuss existing knowledge gaps? Equipment/software advancement needs? Educational/training needs? Specifications/standards?**
    - Develop a framework to move AMG technology forward into the mainstream of highway construction. Review the Iowa DOT developmental specifications as an example.
    - Identify constraints and strategies for moving forward in the following areas:
      - What are the knowledge gaps?
      - What equipment advancements are needed?
      - What education/technology transfer needs exist?
      - What standards/specifications guidelines need to be developed?
- **Topic #3: Intelligent Compaction Specifications and Performance-Based Specifications—Review and discuss outline for IC development specification and performance-based specifications for geotechnical/earthworks**
    - Briefly review the ISSMGE and Mn/DOT specifications.
    - Discuss and debate the developmental specification options.
    - Identify performance parameters that could be used to evaluate or predict the performance of embankments and pavement foundations.
    - Identify a quantitative measurement strategy for each performance parameter, considering in situ testing, performance monitoring, statistical sampling plans, documentation, and similar requirements (existing versus emerging).
    - Identify any perceived gaps in the measurement strategy (e.g., limitations in existing measurement or monitoring technology, verification procedures, or the ability of the performance parameters and measures to predict behavior).
    - Assess how the roles and responsibilities of the agency and contractor could change. Consider: geotechnical investigations, utility identification and relocation, design solution (e.g., selection of the appropriate solution and the design of that solution),

permitting requirements (e.g., disposal of spoils), quality assurance activities (e.g., development of QA/QC and verification plans, sampling and testing, monitoring, documentation), and remediation strategy and implementation (if specified performance is not achieved)

- Identify risks associated with developing a performance specification for embankment construction and pavement foundations. Risk issues could be related to site investigation, design, measurements, testing reliability/accuracy, etc.

In each breakout session, after identifying list of topics to debate, the list was prioritized through discussion and voting. The following is a summary of findings of each group. For some sessions, (#) indicates number of votes given to a topic for prioritization.

Intelligent Compaction for Soils, Aggregate, and HMA 1 — Paul Weigand (Facilitator), Pavana Vennapusa (Recorder)

Prioritized Ranking of 2008 Workshop Road Map Topic Areas

1. Intelligent Compaction Specifications/Guidance (22)
2. Intelligent Compaction and In Situ Correlations (18)
3. In Situ Testing Advancements and New Mechanistic-Based QC/QA (13)
4. Data Management and Analysis (12)
5. Project Scale Demonstration and Case Histories (12)
6. Understanding Roller Measurement Influence Depth (9)
7. Understanding Impact of Non-Uniformity of Performance (9)
8. Intelligent Compaction Technology Advancements and Innovations (8)
9. Intelligent Compaction Research Database (6)
10. Education Program/Certification Program (4)

Proposed Action Plans/Schedule/Responsibilities

1. Intelligent Compaction and In Situ Correlation Studies
    a. Action Plans:
        i. Determine the sensitivity to soil type
        ii. Correlation studies on HMA (full-depth and composite) and WMA
2. Intelligent Compaction Specifications
    a. Action Plans:
        i. Make policy decisions for acceptance
        ii. Suggest using IC for QC
        iii. Make separate specifications for soils/aggregate and HMA
        iv. Recommendations on roller operating parameters
        v. Specify acceptance requirements (e.g., non-uniformity) depending on the compaction layer depth below the surface layer.

vi. Understanding influence depth will impact acceptance requirements
vii. Include elevation and coverage information as part of documentation
viii. Determine what is necessary for IC to qualify for QA
ix. Frequency of data reporting
x. Reporting problematic areas promptly
xi. Data format for reporting
xii. Differentiate responsibilities of owner and contractor in terms of who's collecting and interpreting data
xiii. Option to have a tiered approach by using IC as part of QC and independent QA by owner

b. Schedule and Responsibilities:
   i. Pooled fund studies

3. In Situ Testing Advancements and Mechanistic-Based QC/QA
   a. Action Plans:
      i. Defining mechanistic parameters to be used for QA
      ii. Calibration test strips during construction
      iii. New test equipment
4. Data Management and Analysis
   a. Action Plans:
      i. Explore wireless data transfer capabilities
      ii. Explore effective ways for data storage
      iii. Continued research on geostatistical analysis
      iv. Tools separately for simple (relative easy to use for inspectors) and robust analysis

Intelligent Compaction for Soils, Aggregate, and HMA 2 — Ed Engle (Facilitator), Pavana Vennapusa (Recorder)

Prioritized Ranking of 2008 Workshop Road Map Topic Areas

1. Intelligent Compaction Specifications/Guidance (19)
2. Intelligent Compaction and In Situ Correlations (7)
3. In Situ Testing Advancements and New Mechanistic-Based QC/QA (7)
4. Understanding Impact of Non-Uniformity of Performance (7)
5. Data Management and Analysis (4)
6. Understanding Roller Measurement Influence Depth (4)
7. Education Program/Certification Program (4)
8. Intelligent Compaction Research Database (2)
9. Project Scale Demonstration and Case Histories (1)
10. Intelligent Compaction Technology Advancements and Innovations (1)

Proposed Action Plans/Schedule/Responsibilities

- Intelligent Compaction Research Database
  - Action Items:
    - Identify important elements of a database (design, construction, and long-term performance)
    - Standardize database formats
    - Establish a public domain for data access
- Intelligent Compaction and In Situ Correlation Studies
  - Action Items:
    - Study effect of moisture content
    - Develop relationships with density and stiffness (which is appropriate?)
    - Develop correlations with different portable spot test devices with different machine operation parameters
    - Explore alternate ways of determining target values in a rapid way
    - Research into effects of static vs. dynamic tests on correlations
  - Schedule and Responsibilities:
    - 30-month research study
    - FHWA and Iowa State University
- Intelligent Compaction Specifications/Guidance
  - Action Items:
    - Develop universal/national calibration standards for machines using independent measurements
    - Repeatability and accuracy of GPS and machine values
    - Incentive-based pay factors to contractor
    - Consistency in measurement output units
    - Identify the state of the practice
    - Guidance on how to use the tools
  - Schedule and Responsibilities:
    - Pooled fund study
- Educational Program/Certification Program
  - Action Items:
    - Develop contractor and agency personnel certification and training program
    - Educate on what elements can lead misleading data?
  - Schedule and Responsibilities:
    - Industry/agency
- Understanding Roller Measurement Influence Depth
  - Action Items:
    - Evaluate the measurement influence depth for different material types and layering conditions
    - How geotextiles/fabric/isolated areas of cobbles/water table/foreign objects/utilities in the foundation layers affect the roller values

- Schedule and Responsibilities:
  - Who expertise in instrumentation in soils
  - 18 to 24 months

- In Situ Testing Advancements and Mechanistic-Based QC/QA
  - Action Items:
    - Need of a device that could replicate machine loading conditions and similar influence depth
    - What material property is critical relative to the location of testing in an embankment?
    - Range of index values for a given material type
  - Schedule and Responsibilities:
    - Industry and collaboration with research organizations

- Data Management and Analysis
  - Action Items:
    - What data should be collected?
    - Geostatistics for uniformity characterization
    - What type of data resolution needed?
    - Criteria for data filtering
    - Frequency of data reporting to the owner
    - Extent of detail in the data to be retained (all production data or top few meters or final pass?)
  - Schedule and Responsibilities:
    - IT personnel, statisticians
    - 24 months

- Understanding Impact of Non-Uniformity on Performance
  - Action Items:
    - How do you define uniformity? (variance, coefficient of variation)
    - What is acceptable and what is not?
    - What is the critical area in embankment where it should be uniform?
    - Effect of uniformity in vertical and spatial (on grade) aspects
  - Schedule and Responsibilities:
    - 2 years
    - Agency/University collaboration

Automated Machine Guidance 1
— Charles Jahren and John Hannon (Facilitators), Heath Gieselman (Recorder)

Knowledge Gaps

- Transition to a 3D design practice from a 2D design practice. (8)

- Many DOTs have not worked with machine control technology, and there is lack of awareness. DOTs are still trying to catch up with technology. (5)

- Unfamiliar with file formats and terms relating to design files lack consistency (e.g., TIN, DTM, TTM, XML). (3)
- File types can lack information needed for machine control. (4)
- Surface information and design changes should be left in the hand of the designer, not modified by the contractor. Specifically, this applies to change orders. (2)
- Ability to link design information between segments of construction projects that are created by separate entities (utilities, grade, etc.). (0)
- Communication issues between construction and design communities. (0)

Education/Training

- New operators are not familiar with the fundamentals of survey, which are basis for AMG, resulting in lack of ability to fully take advantage of technology and misuse. (4)
- Certification should be offered for AMG training pertaining to specialization (design, operator, field QC). (2)
- Fundamentals of earthmoving are not practiced and operators are not properly trained by employer. (1)
- Contractor should have employees trained in house or by other means. (1)
- Equipment manufacturers/dealer networks should train on the equipment they produce for clients. (1)
- Addition of technology helps expose knowledge gaps. (0)
- Addition of technology adds a layer of complexity to operator. (0)
- DOT should take active role in training agency personnel in AMG technology. (0)
- Educational institutions should train students with fundamentals and current technologies. (0)
- Operator union has given machine control training in some states. There is a good network of training available in the Midwest. (0)
- Follow-up training for experienced operators. (0)

Specifications/Standards

- Tolerances should be addressed as to what is acceptable for various aspects of construction (rough grade, finish grade, paving, etc.). (9)
- Specification is not encompassing of other technologies (Laser, GPS, Total Station). (3)
- Definitions as to how spatial data presented (pipe elevation given at flow line?). (1)
- Design surfaces have files size limitations based upon equipment capabilities (computer, software, and AMG machine limits). (1)
- When will the best utilization of resources be obtained using AMG and 3D design. (1)
- When are spec and design files available to contractor. (1)
- Some state specifications prohibit machine control by the way they are worded (legal issue). (0)

- Process control checks should be defined for validation (safety net). (0)
- What is the surface that is desired to be delivered to contractor (multiple, pavement, subgrade). (0)
- GPS accuracy requirements. (0)
- Accuracy of individual pieces of equipment and validation. (0)

General

- Currently, the paper document is the legal document; design files are often under a disclaimer for inaccuracy. (2)
- Increased transfer of data increases productivity. (0)

Automated Machine Guidance 2 — Charles Jahren and John Hannon (Facilitators), Heath Gieselman (Recorder)

Knowledge Gaps

- There is limited desire to move toward with pavement AMG by the paving contractors due to initial cost, lack of knowledge and comfort (the string is "safe"), and high QC/QA requirements. (6)
- We don't know what we don't know because we need to have more experience! (5)
- Lack of champions for technology in various agencies (industry, state, contractor). (4)
- Design needs to be in 3D. (3)
- States limit usage due to resistance to "change." (2)
- Old equipment is not functional for technology application so a greater initial investment costs are needed, which may not seem practical. (1)
- ROI information is not easily available. (1)
- Definition of AMG was unclear until exposure at this conference. (0)
- Technology capabilities are unclear. (0)
- Pavement design file and machine control inconsistencies. (0)
- Pavement community finds challenges in steering with AMG. (0)
- Machines are not capable to handle large file sizes and design files must be reduced to allow loading onto machines. (0)
- Time constraints to evaluate data in a real-time environment. (0)
- Transparency between data systems. (0)
- Need large scale "road map" to provide the champions information to work with. (0)
- Terrain is a limitation due to increased costs of survey, design, etc. (0)
- RTK GPS is a "rough grade" system. (0)

Education/Training

- Future conferences/workshops/web-based training need. (7)
- Use of intelligent design tools will increase efficiencies. (2)
- There are difficulties in training; therefore, multiple sessions are needed and hands-on experience is a must and follow-up is needed. (1)
- Training through use and experience. (1)
- "Big 3" companies need to do a better job of supporting paving operations. (1)
- Inspector training is needed in simple awareness as well as technology use. (1)
- Software is needed that designs in 3D and reduces problems between various inputs (utilities, grade, etc.). (1)
- Scan tour for exposure to technologies. (0)
- Manufacture training specifically though simulations including troubleshooting. (0)
- Exposure through open houses and demonstrations. (0)
- Survey industry can provide support to those that need assistance. (0)
- Operators must be trained. (0)
- Pavement Community has been able to achieve 3–5 mm accuracy in the vertical using an augmented GPS system (slope sensors, laser and GPS combination). (0)
- Key aspect: 3D design and electronic plan production and geospatial control of equipment. (0)
- Iowa RTN 2 cm vertical and 1 cm horizontal; be aware of time latency and must be addressed. (0)

Specifications/Standards

- A standard 3D data stream/file format is needed for contractor.
- A standard for QC/QA data to be returned to agency.
- How often should the data be evaluated/monitored (real time, daily, etc.).
- Continued literature review is needed.
- Users input, including those opposed to technology, is needed during creation. (1)
- Proper project selection of initial spec application is important; position yourself for success and give yourself an opportunity to gain experience.
- Unnecessary increases in design size (ethics).
- Specify control in the construction process to deal with surface changes due to as-built construction.

Intelligent Compaction Specifications and Performance-Based Specifications 1 — Tom Cackler and David White (Facilitators), Caleb Douglas (Recorder)

Challenges

- Calibration of IC outputs to known acceptance tools.
- Data filtering—what is needed for acceptance?
- Compatibility of different systems.
- Existing specifications are tied to the technology being used.
- Will never be able to keep up with a "technology specification"; need to shift the technology to the contractor.
- DOTs need to agree upon what end result properties they want to measure.

Goals

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

Discussion

- Stiffness is a good approach and have value to work towards—need to get away from density on soils and aggregate.
- On asphalt, IC is likely to be only QC tool because stiffness is artificially generated by temperature.
- Need guidance on what values are important to test at difference points in fill.
- Using IC data will lead to better quality.
- Traditional methods rely heavily on the experience of the inspector.
- We should set a goal to have developmental specification out in the next year.
- Need to have some certification and calibration of roller and operator.
- Moisture content is critical.
- What electronic output file will be required?
- When will acceptance occur, especially on bigger projects?
- How to define acceptance on variability so IC requirements can be realistic?
- High water table can have big impact on IC values; Minnesota experience is to be about 4 feet above the water table to get out of the zone of influence.
- Need to find independent calibration procedure for roller devices.
- Need anti-data manipulation procedures or safeguards.
- Need to standardize on a value to create a process (stiffness).
- FWD output protocol has a universal output.

Review of Developmental Specifications

- How to move forward with a broadly utilized developmental specification in the US?
  - Owner tools are needed, i.e., software.
  - Work with DOTs that are going to build a project in 2009 and 2010 to form a working group to develop a common framework and identify the tools needed to support the easy application of the specification.
  - Industry buy-in; need to reduce risk and build understanding and training.
  - Need to agree on an index to measure.
  - Roller calibration is needed because spot tests do not measure what the IC roller does (area of influence).
  - **Important Action Item:** Calibration of IC devices with nationwide accepted procedure.

Intelligent Compaction Specifications and Performance-Based Specifications 2 — Tom Cackler and David White (Facilitators), Caleb Douglas (Recorder)

Discussion

- What is the "gold standard"; currently, it is density and moisture; what is needed with IC specifications?
- Look at "superpave" implementation and QC requirements.
- Soils and asphalt will need separate specifications.
- Do we need a "research" level specification?
- Need to address chain of custody of the data in the specification. Is there a owner's device that could go on the machine that could be used to verify to the DOT the data is good?
- FHWA position is to require verification process if they use contractor test results.

Review of Developmental Specifications

- Option 5 may need to be a goal but not where we start. DOTs may be unsure about making large scale changes. Could start with a process that builds into option 5.
- States currently working on developmental IC specifications for soils: Iowa, Minnesota, Texas, Georgia, California (Caltrans), (Alaska on asphalt?), and Utah (perhaps also pooled fund states).
- What is the IC tool for the state agency?
- Don't need to tie GPS with IC.
- Texas will use nuclear gage and perhaps FWD to verify; needs easy, simple, fast test that will also moisture content in the field.

Facilitator Report—Summary

The results of the breakout sessions were analyzed to identify the priorities for advancement in each of the three topics. Prioritization of key issues from each topic was determined based on a detailed review of the recorder notes, finding common topics among sessions, and summarizing the participant votes. The results for this analysis are summarized in the following information.

Intelligent Compaction for Soils, Aggregate, and HMA

Prioritized IC Road Map Elements and Action Items

1. Intelligent Compaction Specifications/Guidance (41)
    a. Data communication between contractor and owner.
    b. Reporting problematic areas.
    c. Standardized data format.
    d. Differentiate owner (e.g., QA) and contractor (e.g., QC) responsibilities.
    e. Separate specifications for soils/aggregate and HMA.
    f. Recommendations on roller operating parameters.
    g. Acceptance requirements (e.g., non-uniformity) depending on the compaction layer depth below the surface layer.
    h. Calibration standards for machines using independent measurements.
    i. Repeatability and accuracy of GPS and machine values.
    j. Incentive-based pay factors to contractor.
    k. Consistency in measurement output units.
    l. Identify the state of the practice.
2. Intelligent Compaction and In Situ Correlations (25)
    a. Correlation studies on HMA and WMA.
    b. Relationships with density and stiffness (which is appropriate?).
    c. Correlations with different in situ test devices with different machine operation settings.
    d. Rapid determination of IC target values.
3. In Situ Testing Advancements and New Mechanistic-Based QC/QA (20)
    a. Rapid test procedures/device to replicate roller loading.
    b. Define mechanistic parameters to be used for QA.
    c. Critical engineering properties relative to the location of testing in an embankment.
4. Understanding Impact of Non-Uniformity of Performance (16)
    a. How do you define uniformity? (variance, coefficient of variation)
    b. What is acceptable and what is not?
    c. What is the critical area in embankment where it should be uniform?

    d. Effect of vertical and spatial non-uniformity on performance.

5. Data Management and Analysis (16)
    a. Explore wireless data transfer capabilities.
    b. Explore effective ways for data storage.
    c. Continued research on geostatistical analysis for uniformity.
    d. Options for simple to robust analysis.
    e. What type of data resolution needed?
    f. Criteria for data filtering.
    g. Extent of detail in the data to be retained.
6. Project Scale Demonstration and Case Histories (13)
    a. Capture barriers to address during implementation.
    b. Compare IC results with conventional operations.
7. Understanding Roller Measurement Influence Depth (13)
    a. Effect of different material types, geotextiles, cobbles, water table, foreign objects, and utilities.
8. Intelligent Compaction Technology Advancements and Innovations (9)
9. Education Program/Certification Program (8)
    a. Contractor and agency certification/training/troubleshooting.
10. Intelligent Compaction Research Database (8)
    a. Standardize storage and documentation.
    b. Database components: design, construction, and long-term performance.
    c. Establish a public domain for data access.

Table 3 shows the top 10 IC technology research and implementation needs that were prioritized by the workshop participants.

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 (16)**
6. **Project Scale Demonstration and Case Histories (13)**
7. **Understanding Roller Measurement Influence Depth (13)**
8. **Intelligent Compaction Technology Advancements and Innovations (9)**
9. **Education Program/Certification Program (8)**
10. **Intelligent Compaction Research Database (8)**

Automated Machine Guidance

Knowledge Gaps and Deficiencies

1. Lack of documented experience and champions. (17)
2. Transition 2D to 3D design practice. (11)
3. File compatibility issues. (7)
4. Limited desire to move toward pavement AMG (stringline is “safe”). (6)
5. Surface information and design changes should be left in the hand of the designer, not modified by the contractor. (2)
6. Currently the paper document is the legal document, design files are often under a disclaimer for inaccuracy. (2)

Education/Training

1. Initial training + experience + follow-up training. (10)
2. Future conferences/workshops/web-based training. (7)
3. Certification. (2)
4. Use of intelligent design tools will increase efficiencies. (2)

Specifications/Standards

1. Acceptable tolerances linked to construction elements (rough grade, finish grade, paving, etc.). (9)
2. Specification inclusive of various technologies (Laser, GPS, Total Station). (3)
3. Object referencing (e.g., top of curb vs. gutter flow line?). (1)
4. Design surface file size limitations (computer, software and AMG machine limits). (1)
5. When will the best utilization of resources be obtained using AMG and 3D design? (1)
6. When are specification and design files available to contractor? (1)
7. Solicit wide ranging review/feedback. (1)

Based on the discussion, four implementation needs were determined, as shown in Table 4.

Table 4. Summary of AMG technology implementation needs

Summary of AMG Technology Implementation Needs

1. **Lack of documented experience and champions + limited desire to transition from 2D to 3D practice (34)**
2. **Education + Training (in-house, manufacturer, web-based) + Conferences + Certification (21)**
3. **Widely accepted specifications on tolerances, requirements, and responsibilities (19)**
4. **Issues with file compatibility + Software capabilities/limitations (9)**

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.

- <u>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).</u>

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).**

Panel Discussion

On day 3, a panel discussion was held for about 1½ hours and moderated by Tudor Van Hampton with ENR, Chicago Bureau. Panel members included Michael Adams (FHWA), Chris Connelly (Bomag America), Terry Rasmussen (Caterpillar), Zhiming Si (TxDOT), Brett Dening (NYSDOT), Bill Kramer (IDOT), Dean Herbst (Iowa DOT), Adam Ross (KYTC), Rebecca Embacher (Mn/DOT), Dick Endres (MDOT). The discussion was mainly centered on the following five key topics:

1. Action items (state DOT, manufacturer, and contractor perspectives).
2. Additional research/development needs for manufacturers.
3. Challenges.
4. Strategies (state DOT perspective).
5. Education/training.

Action Items (State DOT Perspective)

1. Need active involvement by state DOTs.
2. Need more demonstration projects to gain/improve confidence.
3. Need more research on correlations and develop specifications.
4. What QA point measurement should be used as a "gold standard"?
5. Use IC for QC by contractor and perform QA by DOT (use IC as a proof roller to select QA testing).
6. Need champions to overcome bureaucracy constraints.
7. Need upper management people at these workshops.
8. Need more contractor presence at these workshops (workshop timing is a constraint—late February is preferred).

Action Items (Manufacturer Perspective)

1. Need more communication with DOTs and contractors to educate and demonstrate the advantages.
2. Using IC for QC is a good starting point for DOTs.

Action Items (Contractor Perspective)

1. Need detailed specifications on how to implement the technology.
2. Specifications should include machine requirements (e.g., 3D capabilities, GPS, documentation, etc.).

Additional Research/Development Needs for Manufacturer

1. Incorporating the technology on padfoot and heavier machines.
2. Better understanding of the factors (e.g., temperature for asphalt, moisture content for soils) that affect the values to better refine the measurements and improve QC efficiency.

3. Need for effective data management by collaborative effort (e.g., Trimble connected community).
4. Display capabilities to filter inappropriate data (e.g., data collected in non-vibratory mode or reverse direction, etc.).
5. Simple analysis capabilities on display (e.g., % change with each pass, simple statistics).
6. Retrofitting capabilities on existing machines.

Challenges

1. Correlations to current practices/conventionally used measurement and evidence that the technology improves efficiency.
2. Providing machine requirements as part of specifications has not been done in current earthwork specifications.
3. Understanding impact of non-uniformity on performance—need specifications on how often (vertically in an embankment) measurements need to be collected.
4. Change of culture moving from 2D to 3D machine control.
5. Working capital new limitations for implementation.
6. Not enough documented evidence on the efficiency of the technology to convince contractors to use the technology.
7. Develop incentive-based specifications.

Strategies (State DOT Perspective)

1. Conduct demonstration projects and obtain measurements for correlations.
2. Compare current practices with new technology to demonstrate efficiency.
3. Develop draft specifications for implementation on pilot projects.
4. More participation in pooled fund studies.
5. Obtain more information on cohesive soils.
6. Possibility of funding on FHWA?
7. Can ARAP money be used for implementation?
    a. Most projects are already let and specifications cannot be modified now.
    b. Contractor could use it QC.

Education/Training

1. Develop demonstration videos (e.g., McAninch Compaction 101 and GPS 101 videos).
2. FHWA pooled fund studies results are available on YouTube.
3. State DOTs need to develop training/education program.
4. Need for training/certification classes.
5. Use demonstration projects for training state DOTs and contractors.
6. Create a one-stop shop place for information on IC.

Some common themese arose from the panel discussion and were identified as key outcomes, as summarized in Table 6.

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.**

Workshop Outcomes

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

1. Technical information exchange.
2. Prioritized lists of IC technology research, IC and AMG implementation needs, and a refined list of key attributes of IC specifications.
3. Establishment of a network of people interested in partnership and implementation of IC and AMG technologies and new QA/QC testing technologies into earthwork practice.
4. Plans for next year's workshop to further technology exchange and explore opportunities for implementation, education/training programs, and technological advancements.

Next Steps

This workshop provided a platform to exchange ideas between researchers, practitioners, and policy makers and to provide input on the current state of the practice/technology. Some important outcomes from the breakout session and panel discussions were a prioritized IC road map and AMG road map with action items to move forward. Although these road maps are a good starting point, effective and accelerated implementation of these technologies will require "champions" to create opportunities.

The discussion that follows in Tables 7, 8, and 9 provide IC and AMG road maps and action items based on the information derived from the workshop session and the author's viewpoint.

Table 7. Revised IC road map research and educational elements

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 for traditional compaction QC/QA operations and presents new challenges. This research element should focus on data analysis, visualization, and management and be based on a statistically reliable framework that provides useful information to assist with 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

contractors 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 elements 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, 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 guidebooks 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 a 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 assessing the 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, and 9.

*2008 Workshop Ranking

Table 8. AMG road map research and educational elements

AMG Road Map Research and Educational Elements

1. **Demonstration Projects and Case Histories.** The product from this research element will be documented experiences and results from pilot projects where AMG is implemented as part of the project specifications. The projects should include a wide range of material and site conditions across the United States (e.g., earthwork cut and fill, fine grading, paving, etc.). The project-level case histories should include interviews from contractors and field inspectors. Conclusive results with respect to the benefits of AMG implementation by comparing it with conventional methods and field experiences should be reported and analyzed.

2. **Education/Certification/Training Program.** This educational element is the key to accelerating the implementation of AMG technology. Materials generated for this element should include a broadly accepted and integrated certification program than can be delivered through short courses, future conferences, and via the web for rapid training needs. Operator/inspector guidebooks and troubleshooting manuals should be developed. The

educational programs need to provide clear and concise information to contractors and state DOT field personnel and engineers. A potential outcome of this element would be materials for NHI training courses.

3. **AMG Specifications/Guidance on Tolerances/Requirements/Responsibilities.** This research element will result in widely accepted specifications inclusive of various AMG technologies (e.g., last GPS, total station, etc.), with guidelines on acceptable tolerances specific to construction elements (i.e., paving, fine grading, etc.). The specifications should clearly outline the achievable tolerances (utilizing information from element 1), requirements, and responsibilities (i.e., QC/QA testing and frequency, responsibility for the 3D model, schedule of design files' availability to the contractor, etc.). This work should build on existing AASHTO and state DOT specifications.
4. **Standardization of File Type Formats and Data Transfer Protocols.** This is an important research element in successful implementation of the specifications and will be an important input to element 3. File compatibility and computer/software issues can lead to frustration with delays on construction sites. Standardization of the file formats and data transfer protocols as part of the specifications will significantly help overcome this obstacle. This element should be addressed as part of element 2.

Table 9. Action items for advancing IC road map and AMG road map

Action Items for Advancing IC Road Map and AMG Road Map

1. Develop six case histories (technical briefs) to demonstrate the benefits of the technologies
2. Conduct six webinars to facilitate training and technology transfer
3. Create a Specifications Technical Working Group to coordinate efforts
4. Regularly update the Earthworks Engineering Research Center web site (www.eerc.iastate.edu)
5. Explore the possibility of conducting a National Highway Institute course on IC and AMG technologies
6. Identify current research gaps, develop problem statements for needed research, and identify key research partners

Appendices

Appendix A: Workshop Agenda

Intelligent Construction for Earthworks
Sheraton Hotel, West Des Moines, Iowa
April 14–16, 2009

Sponsors: Iowa Department of Transportation and Iowa State University Earthworks Engineering Research Center (EERC)

Mission: This event provides an opportunity for participants to exchange ideas and experiences in using intelligent construction technologies. The goal is to increase participants' knowledge and identify strategies to advance use of these tools to provide verifiable results that are appropriate for both contractor quality control and owner acceptance decisions.

Day 1—Tuesday, April 14, 2009

6:30 a.m. Breakfast and Registration

AM Moderator: Sandra Larson, P.E., Iowa DOT

8:00 **Welcome and Workshop Mission**—Sandra Larson

Why are we here?—John Adam, P.E., Iowa DOT

8:20 **Review of Outcomes from 2008 Workshop**—Dr. David White, Director, EERC, Iowa State University

9:00 **Joint Rapid Airfield Construction (JRAC): U.S. Military's New Approach to Contingency Airfield Construction**—Dr. Gary Anderton, Chief, Airfields and Pavements Branch, U.S. Army Engineer Research and Development Center

10:00 **Break**

10:15 **IC Case Histories for Soil, Aggregate, and HMA**—Dr. David White, Dr. Pavana Vennapusa, Rachel Goldsmith, and Luke Johanson

11:15 **Mn/DOT Experience with LWD and IC Implementation**—Rebecca Embacher and Tim Andersen, Mn/DOT

12:00 p.m. **Lunch (buffet)**

PM Moderator: Lisa Rold, FHWA, Iowa Division

1:00 **The Mars Exploration Rovers: Five Years of Exploring the Martian Surface**—Dr. Rob Sullivan, Cornell University, NASA's Mars Explorer Rover Project

2:30 **Break**

2:45 **Statewide Iowa RTK-GPS**—Mike Jackson, Iowa DOT

3:00 **GPS Technology in Planning, Design and Construction Delivery**—Prof Jeff Hannon, University of Southern Mississippi; GPS Automatic Grade Control Systems, Engineering Distance Education—Dr. Charles Jahren, Iowa State University; NCHRP 10-77—Dr. David White

3:25 **New Approach for Asphalt IC**—Dr. Sesh Commuri and Dr. Musharraf Zaman, University of Oklahoma

3:45 **Participating State DOT Briefings (IA, MN, WA, LA, VA, GA, IL, WI, KY, KS, TX, MO, MS, MI, NY, SD)**

4:45 **Wrap-up, Review of Workshop Mission, Tomorrow's Session**—Sandra Larson

Day 2— Wednesday, April 15, 2009

6:30 **Breakfast**

AM Moderator: Tom Cackler, P.E., National Concrete Pavement Technology Center, ISU

7:30 **Industry/Equipment Manufacturer Overviews**

9:30 **Break**

9:45 **Charge to the group**—Tom Cackler

10:00 **Session 1 – Break out discussion groups (1 group on each topic)**

- Technical aspects of IC for soils, aggregate, and HMA (e.g. data format, measurement technology, software, etc.)
- Implementation aspects (e.g., design tools, education/training, case histories)
- Review of developmental specification and performance-based specifications

12:00 **Lunch (buffet)—Geo-Mobile Lab and FWD Lab Tours in South Parking Lot**

1:00 **Session 1 continues**

1:45 **Break**

2:15 **Session 2—Breakout discussion groups (1 group on each topic)**

- Technical aspects of IC for soils, aggregate, and HMA (e.g. data format, measurement technology, software, etc.)
- Implementation aspects (e.g., design tools, education/training, case histories)
- Review of developmental specification and performance-based specifications

4:45 **Adjourn**

Day 3— Thursday, April 16, 2009

6:30 **Breakfast**

Moderator: Tudor Van Hampton, Associate Editor, Engineering News-Record (ENR)

7:30 **Summary of Facilitators' Reports from Day 2 Discussions**

9:00 **Break**

9:30 **Panel Discussion and Questions**-Tudor Van Hampton

- State DOT representatives
- Contractor representatives
- Industry representatives

10:30 **Audience Implementation Exercise**

11:00 **Wrap-up and Discussion of Next Steps**—Sandra Larson

11:15 **Workshop Evaluation**

11:30 **Adjourn**

Appendix B: Workshop Attendees

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Appendix C: Iowa DOT Developmental Specifications for GPS Machine Control Grading (DS-01119)

DS-01119
(Replaces DS-01103)

Iowa Department of Transportation

DEVELOPMENTAL SPECIFICATIONS
FOR
GLOBAL POSITIONING SYSTEM MACHINE CONTROL GRADING

Effective Date
November 18, 2008

THE STANDARD SPECIFICATIONS, SERIES 2001, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

01119.01 GENERAL.
This specification contains requirements for grading construction utilizing Global Positioning System (GPS) machine control grading techniques and shall be used in conjunction with Section 2526, of the Standard Specifications.

The Contractor may utilize grading equipment controlled with a GPS machine control system in the construction of the roadway embankment.

The plans indicate the areas of the project where the Contracting Authority is providing electronic surface models of the roadway embankment construction. The remaining areas may be constructed with conventional construction survey techniques unless the Contractor chooses to build the required surface models to facilitate GPS machine control grading for those areas at no additional cost to the Contracting Authority.

The Contractor may use any type of GPS machine control equipment and systems that results in achieving the existing grading requirements. The Contractor shall convert the electronic data provided by the Contracting Authority into the format required by their system.

01119.02 EQUIPMENT.
All equipment required to accomplish GPS machine control grading shall be provided by the Contractor and shall be able to generate end results that meet the Standard Specifications.

01119.03 CONSTRUCTION.

A. Contracting Authority Responsibilities.

1. The Engineer will set the initial horizontal and vertical control points in the field for the project as indicated in the contract documents.

2. The Engineer will provide the project specific localized coordinate system. The control information utilized in establishing the localized coordinate system, specifically the rotation, scaling, and translation can be obtain from the Engineer upon request.

3. The Contracting Authority will ~~provide~~ make available the data listed below in an electronic format ~~with the proposal form~~. This information is available for a fee at: http://www.ia.bidx.com/main/index.html. The Contractor will be required to purchase an online account to obtain the electronic data.

   No guarantee is made that the data systems used by the Engineer will be directly compatible with the systems used by the Contractor.

   Article 1105.04 of the Standard Specifications shall apply with the additional clarification that information shown on the plans shall govern over the provided electronic data.

   This information shall not be considered a representation of actual conditions to be encountered during construction. Furnishing this information does not relieve the Contractor from the responsibility of making an investigation of conditions to be encountered including, but not limited to site visits, and basing the bid on information obtained from these investigations, and the professional interpretations and judgment of the Contractor. The Contractor shall assume the risk of error if the information is used for any purposes for which the information was not intended.

   Any assumptions the Contractor makes from this electronic information shall be at their risk. The Contracting Authority will develop and ~~provide~~ make available electronic data to the Contractor for review as part of the contract documents. The Contractor shall independently ensure that the electronic data will function in their machine control grading system.

   The files that are ~~provided~~ made available were originally created with the computer software applications MicroStation (CADD software) and GEOPAK (civil engineering software). The data files will be ~~provided~~ in the native formats and other software formats as described below. The Contractor shall perform necessary conversion of the files for their selected grade control equipment. The Contracting Authority will ~~furnish~~ make available to the Contractor ~~with~~ the following electronic data files:

   a. CAD Files:
   - GEOPAK TIN files representing the design surfaces.
   - GEOPAK GPK file containing all horizontal and vertical alignment information.
   - GEOPAK documentation file describing all of the chains and profiles.
   - MicroStation primary design file.
   - MicroStation cross section files.
   - MicroStation ROW data file.
   - MicroStation photogrammetry and text files.

   b. Machine Control Surface Model Files:
   - ASCII format.
   - LandXML format.
   - Trimble Terramodel format.

   Note: TIN files and surface model files of the proposed finish grade include the topsoil placement where required in the plans.

   c. Alignment Data Files:
   - ASCII format.
   - LandXML format.
   - Trimble Terramodel format.

4. The Engineer may perform spot checks of the Contractor's machine control grading results, surveying calculations, records, field procedures, and actual staking. If the Engineer determines that the work is not being performed in a manner that will assure accurate results,

the Engineer may order the Contractor to redo such work, to the requirements of the contract documents, at no additional cost to the Contracting Authority.

B. Contractor's Responsibilities.

1. The Contractor shall provide the Engineer with a GPS rover for use during the duration of the contract. At the end of the contract, the GPS rover unit will be returned to the Contractor. This unit shall have the same capabilities as units utilized by the Contractor. The Contractor shall provide 8 hours of formal training on the Contractor's GPS machine control systems to the Engineer.

2. The Contractor shall review and apply the data provided by the Contracting Authority to perform GPS machine control grading.

3. The Contractor shall bear all costs, including but not limited to the cost of actual reconstruction of work, that may be incurred due to errors in application of GPS machine control grading techniques. Grade elevation errors and associated quantity adjustments resulting from the Contractor's activities shall be at no cost to the Contracting Authority.
4. The Contractor shall convert the electronic data provided by the Contracting Authority into a format compatible with their system.

5. The Contractor understands that any manipulation of the electronic data provided by the Contracting Authority shall be taken at their own risk.

6. The Contractor shall check and recalibrate, if necessary, their GPS machine control system at the beginning of each work day.

7. The Contractor shall meet the same accuracy requirements as conventional grading construction as detailed in the Standard Specifications.

8. The Contractor shall establish secondary control points at appropriate intervals and at locations along the length of the project and outside the project limits and/or where work is performed beyond the project limits as required at intervals not to exceed 1000 feet (300 m). The horizontal position of these points shall be determined by static GPS sessions or by traverse connection from the original baseline control points. The elevation of these control points shall be established using differential leveling from the project benchmarks, forming closed loops. A copy of all new control point information shall be provided to the Engineer prior to construction activities. The Contractor shall be responsible for all errors resulting from their efforts and shall correct deficiencies to the satisfaction of the Engineer and at no additional cost to the Contracting Authority.

9. The Contractor shall preserve all reference points and monuments that are established by the Engineer within the project limits. If the Contractor fails to preserve these items they shall be reestablished by the Contractor shall reestablished at no additional cost to the Contracting Authority.

10. The Contractor shall set hubs at the top of the finished subgrade at all hinge points on the cross section at 1000 foot (300 m) intervals on mainline and at least two cross sections on the side roads and ramps. These hubs shall be established using conventional survey methods for use by the Engineer to check the accuracy of the construction.

11. The Contractor shall provide controls points and conventional grade stakes at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for the construction of drainage and roadway structures.

12. At least one week prior to the preconstruction conference, the Contractor shall submit to the Engineer for review a written machine control grading work plan which shall include the equipment type, control software manufacture and version, and the proposed location of the local GPS base station used for broadcasting differential correction data to rover units.

01119.04 METHOD OF MEASUREMENT.
The bid item for GPS Machine Control Grading will be measured and paid for at the lump sum contract price.

01119.05 BASIS OF PAYMENT.
The bid item for GPS Machine Control Grading will be paid for at the lump sum contract price. This payment shall be full compensation for all work associated with preparing the electronic data files for use in the Contractor's machine control system, the required system check and needed recalibration, training for the Engineer, and all other items described in Article 01119.03, B of this Developmental Specification.

Delays due to satellite reception of signals to operate the GPS machine control system will not result in adjustment to the "Basis of Payment" for any construction items or be justification for granting contract extensions.

Appendix D: Photos

Appendix E: Workshop Evaluation Comments

Did the workshop meet your expectations?

- More than expected, I believe this needs to continue.
- Yes, far exceeded (3 responses); well-organized and facilitated; very good and helpful; very educational.
- Having no expectations to start, the workshop was extremely valuable in showing what is possible now and where we can realistically expect to go in the future.
- Yes, Day 1 was a little weak, many presentations.
- I was hoping to learn from other states on their IC experience.
- I was able to understand where we are.
- Yes, a lot of useful information. I still have a lot to digest at this time.
- Yes, I was pleasantly surprised by all the great content and speakers.
- As a first time attendee, Yes!!!
- Yes, but it was difficult to have expectations as this was my first.
- Mostly, for someone with little knowledge in IC it was not always clear if the goal was to learn more or jump forward and implement a technology that still needs development.

What was the most useful part of the workshop?

- Networking/Interaction between industry, education, IT, DOTs in general, & FHWA (7)
    - Meeting people who are dealing with this as well and what problems and solutions they have encountered.
    - Interaction with peers and an opportunity to learn new technologies.
- Technical Presentations (2)
- Industry/Mfg Presentations, general and detailed exposure to IC, JRAC and Mars presentations were great.
- The technical presentations were useful but seemed to build upon last years workshop. Since I did not attend last year, it took awhile to get up to speed.
- Hearing opinions and concerns from the DOTs (it really surprised me there is such a wide gap in the IC knowledge across the DOTs).
- Identifying issues.
- Working sessions (12) helped me see where various groups are at with their IC developments.
    - Working sessions continue creation of a network and tools to get this technology implemented.
- The barriers to implementation.
- Panel discussion (4).

- Specification workshop. (2)
- Summary of facilitators reports. (2)
- Discussion of QC-QA Process.
- Road map review, list of attendees, general discussion.
- Need to have things explained at the basic level. Most have limited knowledge. Basic grass roots level session is critical to get buy in.
- Dr. White's expertise in the subject area. Excellent teacher and has answered many questions.
- I was able to understand where we are.
- Case histories and state reports.
- Learning about a new tool that will be part of future construction.
- General information, knowledge gained.
- Information to take back to my state.

What was the least useful part of the workshop?

- Working sessions.
- Difficult question to answer. Narrow in on goals.
- Discussion needs more decision maker influence.
- State DOT briefings. (2)
- Hour long lunches, try to use working lunch format.
- Mars presentation, lots of fun and I enjoyed it but did not contribute substantially to the topic of IC. (5)
- Guest speakers were interesting but not very useful. (2)
- Presentations not useful in my field (unavoidable because of the diverse amount of people).
- Day 1 presentations.
- Some theoretical and mechanical analysis of IC test results.
- Some of the manufacturers' presentations seemed a little long. At the working sessions several of the points seemed to be brought up over and over and although the discussion was helpful sometimes, it would have been better to move on.
- Some of the spec writing process/aspects were repetitive.
- The lack of forward progress by individual DOTs, barriers of IC technology.

What suggestions would you make to improve the next workshop?

- More reports on demo projects or visit demo projects. (5)
- There was mention of comparisons between blind compaction and IC compaction, a

presentation on this would be interesting; more interesting presentations on cohesive soils, non-uniform soils.

- More hands on items manufactures having demos of their equipment even just a simulator would be great, videos of the pilot projects.
- Provide presentations on each step of the process ending with an overview or report on a demo project.
- Have separate breakout sessions for 1. State DOTs 2. Contractors 3. Equipment vendors 4. Software and then each group present their major concerns.
- NCHRP results of effort?
- Contractor participation. (4) The voice of the industry needs to be vocal.
- What is the military doing? How does immigration input current understanding of tech. advancement?
- February or early March meeting should involve more contractors. (2)
- Include designers, executive level management; cleaner vision of intelligent construction.
- Review what milestones from the first and second workshops have been completed.
- Suggest to presenters to provide some energy, some on the first day were hard to concentrate on.
- Focus on a few topics to narrow the scope; eliminate HMA and machine guidance.
- Some breakout on the first day; long first day for out of state folks.
- Include a portion summarizing findings from current and completed research, pooled fund studies, NCHRP, AASHTO, etc.; case histories from states who have tried IC projects and/or demo projects; tt would be useful to have more contractors opinions.
- Have more facets of those involved represented from design to contractors to QA.
- More question and answer like working sessions but with the whole group.
- Another workshop would be very helpful. The networking/partnerships is needed and important.
- What was learned over the summer? Need to go over the 4 material properties and how they relate to each other (everybody needs basic training).
- If we can see how we advance these, especially action items, it would be good.
- I think it might be nice to divide one of the days (1st day) and technical forums into IC related to soils and IC related to HMA. IC can be used for both purposes, but IC for soils is so much further along than IC for HMA, so we kind of need to address that.
- Maybe more time for state DOT briefings. Would be good to have more technical presentations, perhaps an overview of a project in depth, i.e., start to finish, implementation, technologies tried, lessons learned.
- AV equipment needs help! Sound, microphones, pointers, etc.

- Compress info into 1½–2 days; maybe one overnight. (2)
- Technical presentations on machine values and correlations, equipment limitations.
- More technical in nature to highlight the research work.

Additional Comments

- Many thanks to all other organizers and contributors and Iowa DOT for financial contributions!
- Thank you for your time and effort put towards this workshop.
- Just continue.
- Appreciated the PF groups paying for this workshop and our ability to be here. If IC doesn't move forward over the next year, and I think it will take our contractors efforts to push it, I'm not sure Missouri DOT has much input to the process. We will disseminate the information through the DOT and see what happens. Thanks for the opportunity; you put on a first-class workshop.

Appendix F: Geotechnical Mobile Lab Brochure

EERC
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The Earthworks Engineering Research Center (EERC) is part of the Center for Transportation Research and Education (CTRE) at Iowa State University. The mission of the EERC is to increase highway performance in a cost-effective manner by developing and implementing methods, materials, and technologies to solve highway construction problems in a continuing and sustainable manner.

MOBILE geotech research lab

A custom-built 44-foot trailer fully equipped for conducting a comprehensive suite of state-of-the-art lab and in situ geomaterials tests

OCTOBER 2008

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EERC
EARTHWORKS ENGINEERING RESEARCH CENTER

ctre
Center for Transportation Research and Education

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

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 200 sieve shaker


Humbolt rapid soil grinder


Video presentation screen


Proctor "Ploog" soil compactor


Liquid and plastic limits testing equipment