Transportation Learning Network

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Implementation of Intelligent Compaction Technologies for Road Construction

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Outline

- Introduction
- Background of Intelligent Compaction
- Surveys
- Economic Analysis
- Conclusions and Recommendations

Goal and Objectives

- **Goal**: Improve Pavement Quality and Road Safety, and Reduce Construction Costs and Duration.
- **Objectives**:
  – Examine current Intelligent Compaction (IC) technologies and practices
  – Evaluate IC implementation across the states
  – Develop framework for economic analysis of IC

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Current Road Compaction

- Current roadway compaction methods are highly operator dependent
- Roller passes are often inconsistent
- Coverage of quality control and assurance (QC/QA) tests are minimal; less than 1% of roadway section

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Intelligent Compaction (IC)

1: Accelerometer
2: Controller
3: LCD Display
4: GNSS Antenna
5: Color Display
6: GNSS Receiver
7: Angle Sensor

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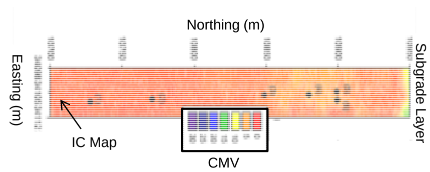
Intelligent Compaction (IC)

- **Characteristics**:
  - Continuous assessment of soil/pavement stiffness
  - Roller operation with automatic adjustment
  - Integrated GPS for real time mapping of stiffness



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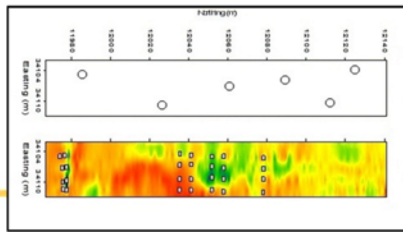
Potential Benefits of IC

- Higher quality compaction
- Improve roadway safety
- Improve coverage for QC/QA testing
- Improve roller pass consistency
- Reduce construction and maintenance costs

In-Situ Tests < 1 %

IC = 100 %



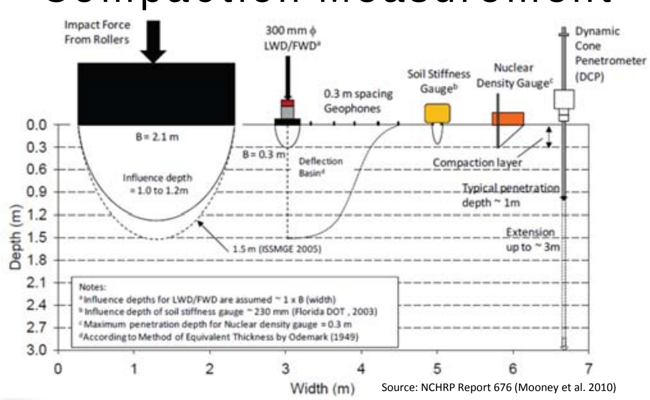
IC Equipment

IC for Soil Compaction

Vendor	Model	Model No	IC-MV	Software
Ammann/Case	ACEplus	SV	K_b	ACEplus
Bomag	VarioControl	BW213-4BVC	E_{vib}	BCM05
Caterpillar	AccuGrade	CS44-CS78 CP54-CP74	CMV, MDP	AccuGrade, VisionLink
Dynapac	DCA-S	CA 152-702	CMV	DCA-S
HAMM (Wirtgen)	HCQ		HMV	HCQ
Sakai	CIS	SW850-SW900	CCV	AithionMT
Volvo	Trimble retrofit		CMV	SiteVision, VisionLink

IC-MV: Intelligent compaction measurement values
ACEplus: Ammann Compaction Expert – Plus DCA – S
K_b: Ammann soil stiffness value
GPS: Global Positioning System
E_{vib}: Vibration Modulus
CMV: Caterpillar and Dynapac Compaction Meter Value
MDP: Caterpillar Machine Drive Power
CIS: Sakai Compaction Information System
CCV: Sakai Compaction Control Value
DCA: Dynamic Compaction Analyzer
HCQ: HAMM Compaction Quality
HMV: HAMM Measurement Value

Compaction Measurement



Source: NCHRP Report 676 (Mooney et al. 2010)

Veta Software

- Data Management Tool: MV and GPS data stored to on-board computer
- Data can be uploaded to computer for analysis
- Provides a map of compaction data
- Builds correlations with in-situ data
- Determine if section meets QC/QA specifications
- Software is free

http://www.intelligentcompaction.com/veta/

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Current Compaction Specifications

State DOTs use a variety of methods for quality control and quality assurance (QA/QC)

- Soil and Aggregate Layers
  - Nuclear Gauge, Proctors, Sand Cone, etc.
- Pavement
  - Cores, Nuclear Gauge, Non-Nuclear Gauge/ Electric Density Gauge

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QC/QA Specifications with IC

- Current specifications require in-situ testing (DCP, sand cone, nuclear gauge, cores, etc.)
- Three options using IC for QC/QA:
  - Option 1: Use IC to identify weakest area and apply in-situ test
  - Option 2 (a or b): Measure compaction uniformity
  - Option 3 (a, b or c): Create target values between MV and in-situ/lab test values on a control strip prior to construction

IC Specifications

- FHWA has developed specifications for use by transportation agencies
  - Currently being adapted to AASHTO specifications
- 18 states are in the process of drafting or adopting IC specifications
- More than 30 states have conducted workshops or demonstration projects for IC

http://www.intelligentcompaction.com/projects/specifications/

IC Specifications

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Wyoming Survey

Total Respondents = 79

Do you have any concerns with IC?

Answer Options	Response Percent	Response Count
Cost	33.3%	24
Reliability of data	26.4%	19
Reliability and durability of technology	19.4%	14
Not a specified quality control/assurance method	22.2%	16
Lack of operator ability and/or time and cost to train operators	22.2%	16
Unfamiliar with technology	20.8%	15
There are no concerns	19.4%	14
Other		9
	answered question	**72**
	skipped question	**7**

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National Survey

- Total Respondents = 32

National Survey

DOT Knowledge and Use of IC

Which aspects of intelligent compaction is your agency familiar with? [Select all that apply]

Answer Options	**Response Percent**	**Response Count**
Operation of intelligent compaction rollers	76.7%	23
Technology used during intelligent compaction	90.0%	27
Cost and benefits	50.0%	15
Quality Control and Assurance Standards	56.7%	17
None of the above	6.7%	2
Other (please specify)		5
	answered question	**30**
	skipped question	**2**

National Survey

DOT Concerns about Using IC

Does your agency have any concerns with the use of intelligent compaction for soil or pavement materials? [Select all that apply]

Answer Options	Response Percent	Response Count
There are no concerns	10.3%	3
Cost	31.0%	9
Reliability of data	34.5%	10
Ability to have it approved as a quality assurance technique by policymakers	41.4%	12
Less strict than current quality assurance methods	17.2%	5
Lack of staff knowledge to confirm data	41.4%	12
Unfamiliar with technology	20.7%	6
Other (please specify)		11
	answered question	**29**
	skipped question	**3**

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National Survey

IC QC/QA Specifications

Has your agency ever drafted quality control or quality assurance standards for intelligent compaction? [Select one]

Answer Options	Response Percent	Response Count
Yes, quality assurance standards for intelligent compaction have been adopted	14.3%	3
Yes, draft standards have been completed and are awaiting adoption	19.0%	4
Yes, we are in the process of drafting standards	23.8%	5
No, but we plan on drafting standards	4.8%	1
No, and we do not plan on drafting standards at the current time	38.1%	8
Other (please specify)		11
	answered question	**21**

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National Survey

Costs Associated With IC

What changes in bid costs or in-house costs does your agency incur with compaction services utilizing intelligent compaction? [Select one]

Answer Options	Response Percent	Response Count
An increase in cost	31.3%	10
About the same cost	0.0%	0
A decrease in cost	0.0%	0
Not sure	34.4%	11
Not applicable	34.4%	11
	answered question	**32**
	skipped question	**0**

National Survey

Costs Associated With IC:

- Only 3 respondents mentioned that had information related to long-term costs
- One respondent, Texas, indicated that the long-term period yielded “higher benefits than costs”

Economic Analysis

- Limited study on benefits and costs
- Framework for economic analysis
  - Construction Cycle + Cost
  - Roadway Lifecycle
- Two case examples:
  - Case Study 1: Pavement Overlay
  - Case Study 2: New Construction

Construction Cycle and Cost

- **Construction Cycle** = Time period begins with preparation for roadway compaction
- **Construction Cost** = (Compaction Time in Hours) x [(Roller Cost Per Hour) + (Roller Operator Cost Per Hour) + (GPS Cost Per Hour)] + [(QC/QA Cost Per Area) x (Area)] (Eq. 5.1)

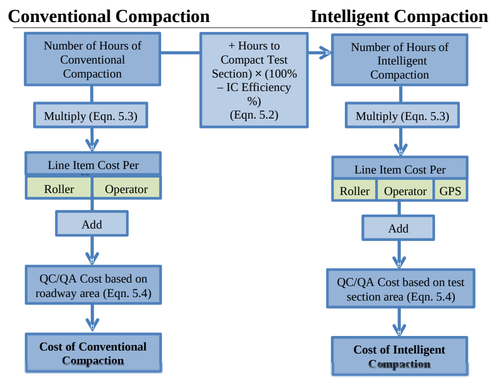
Construction Cycle and Cost

- **IC Hours** = (Conventional Compaction Hours for Roadway Section + Conventional Compaction Hours for Test Section) x (100% − IC Efficiency %) (Eq. 5.2)
- **Cost Per Line Item** = (Hourly Rate of Line Item Cost) x (Hours) (Eq. 5.3)

Construction Cycle and Cost

- **QA/QC Cost** = (Hours to Perform QC/QA) x (Area of QC/QA Per Hour) x (Cost of QA/QC Per Area) (Eq. 5.4)

Framework for Cost



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Roadway Lifecycle

- IC provides a more uniform compaction and extends pavement life
- **Cost Per Lane-mile Per Year** = (Cost of Roadway Per Lane-mile) / (Service Life in Years) (Eq. 5.5)

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Example 1: Pavement Overlay

- A single lane-mile, 2-inch asphalt overlay
- 500-foot IC calibration section
- Cost data obtained from equipment manufactures, contractors, and research
- 30% IC roller efficiency (Briaud and Seo, 2003)
- Roadway lifecycle increase of 2.6 times (Chang, et al., 2012)

Cost Data

Item	Unit Cost ($)/ Quantity	Source
	Construction Costs	
QC/QA per square yard	$ 0.04	Simon Contractors, WY (Bastian, 2014)
IC Reduction in compaction cost	30%	Briaud & Seo (Briaud & Seo, 2003)
Lane width, feet	12	Assumption
IC to conventional QC/QA cost	10%	NCHRP 676 (Mooney, et al., 2010)
Conventional roller cost per hour	$ 36	High Country Construction, WY (Newman, 2014)
IC pavement roller cost per month	$ 7,500	Sakai America (Jones, 2014)
Roller operator per hour	$ 30	High Country Construction, WY (Newman, 2014)
Conventional compaction hours/lane-mile	10	High Country Construction, WY (Newman, 2014)
Compaction cost per square yard	$ 0.20	Simon Contractors, WY (Newman, 2014)
GPS System rental per year	$ 1,800	Trimble (Trimble Navigation Limited, 2014)
Test Section Length, feet	500	NCHRP 676 (Mooney, et al., 2010), DOT IC Specs (The Transtec Group, Inc, 2014)
Work hours per week	40	Assumption
	Lifecycle Costs	
Increased service life with IC, multiplier	2.6	(Chang, Gallivan, Horan, & Xu, 2012)
Average asphalt life, years	10	Average overlay service life
Cost per lane-mile	$ 250,000	WYDOT (Wyoming Department of Transportation, 2011), Caltrans (Caltrans, 2011 Woodland (City of Woodland, 2008)

Example 1: Construction

- 37% decrease in cost from IC to conventional compaction

	Conventional Compaction				Intelligent Compaction			
Item	Cost per Unit	Unit	Number of Units	Total Cost	Cost per Unit	Unit	Number of Units	Total Cost
Roller	$ 36.00	hour	10	$ 360.00	$ 42.61	hour	7.7	$ 328.10
Operator	$ 30.00	hour	10	$ 300.00	$ 30.00	hour	7.7	$ 231.00
GPS	n/a	n/a	n/a	n/a	$ 0.89	hour	7.7	$ 6.85
QC/QA	$ 0.04	yd^2	7040	$ 281.60	$ 0.04	yd^2	667	$ 26.68
Total				$ 941.60				$ 592.63

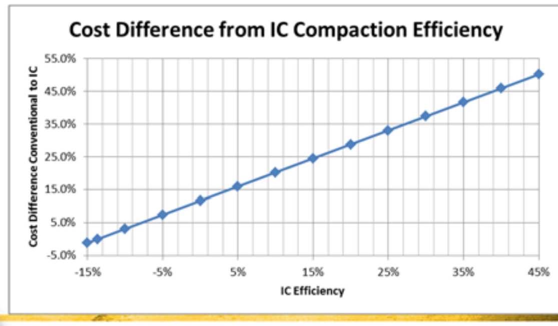
Example 1: Roadway Lifecycle

- $15,385 per year benefit with IC compacted section

Compaction Type	Service Life (years)	Cost Per Year	Cost Over 26 years
Conventional	10	$ 25,000	$ 650,000
Intelligent	26	$ 9,615	$ 250,000
Difference	-16	$ 15,385	$ 400,000

Example 1: Sensitivity Study

- IC Efficiency breaks even when IC roller efficiency is negative 13.7% (savings on QC/QA)



Example 2: New Road

- Single lane-mile, new construction
  - o Subgrade: 8”; Subbase: 8”; Base: 8” ; Binder: 4” ; Surface: 2”
- 500-foot IC calibration section
- 30% IC roller efficiency (Briaud and Seo, 2003)

Cost Data

Construction Cycle		
Item	**Cost / Quantity**	**Source**
QC / QA per square yard per layer	$ 0.04	Simon Contractors, WY
IC Reduction in Compaction Cost	30%	Briaud & Seo, 2003
Lane Width, feet	12	Assumption
IC to Conventional QC/QA cost	10%	NCHRP 676 based on test section size
Conventional Soil Roller Cost per hour	$ 34.03	Wagner Rents, Fort Collins, CO
Conventional Pavement Roller Cost per hour	$ 36.00	High Country Construction, WY
IC Soil Roller Cost per month	$ 7,000	Sakai America
IC Pavement Roller Cost per month	$ 7,500	Sakai America
Operator Cost per hour	$ 30.00	High Country Construction, WY
Number of passes per layer	6	Assumption
Average Roller Speed (mph)	3 and 8	Assumption
Layer Thickness, inches (Subgrade/ subbase/ base/ binder/ surface)	8 / 8 / 8 / 4 / 2	Assumption
GPS System, per year	$ 1,800.00	Trimble

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Compaction Hours

- **Compaction Hours** = [ROUND TO INTEGER (Lane width/Roller Width)] × (Number of passes) × (Roadway length)/(Roller speed) (Eq. 5.8)
  - Compaction Hours per soil layer = [ROUND TO INTEGER (12 ft/7 ft)] × (6 passes) × (1 mile)/(3 miles per hour) = 4 hrs
  - Compaction Hours for three soil layers
    = 4 hrs × 3 = 12 hrs.
  - Compaction Hours for two pavement layers
    = 4 hrs × 2 = 8hrs.

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Example 2: Construction

- IC provides 54% savings compared to conventional compaction at 3 mph

Conventional Compaction					Intelligent Compaction			
Item	**Cost per Unit**	**Unit**	**Number of Units**	**Total Cost**	**Cost per Unit**	**Unit**	**Number of Units**	**Total Cost**
Soil Roller	$ 34.03	hour	12.0	$ 408.41	$ 39.77	hour	9.2	$ 365.83
Pav. Roller	$ 36.00	hour	8.0	$ 288.00	$ 42.61	hour	6.1	$ 261.31
Operator	$ 30.00	hour	20.0	$ 600.00	$ 30.00	hour	15.3	$ 459.90
GPS	-	-	-	$ -	$ 0.89	hour	15.3	$ 13.64
QC/QA	$ 0.20	sq yd	7040	$ 1,408.00	$ 0.20	sq yd	667	$ 133.40
Total				$ 2,704.41				$ 1,234.08

Conclusions

- IC improves roadway quality and decreases roadway related costs.
- IC provides 100% coverage of compaction.
- Most Wyoming professionals are supportive of implementation of IC, but they concern about cost and the reliability of data.
- One-third of the national survey respondents believed that roadway construction with IC currently involve an increase in cost.
- Another one-third were not sure on the cost.

Conclusions

- IC, when used effectively, can produced a 37% decrease in construction costs based on an asphalt overlay on one lane-mile long roadway and a 54% decrease in costs on a one lane-mile new roadway section.
- Improved pavement performance based on compaction uniformity using IC can yield approximately $15,000 per lane mile per year in cost savings.

Recommendations

1) Working with the FHWA to secure funding and a site for an IC demonstration project.
2) Adapting IC QC/QA specifications to be used during the demonstration project as a special provision.
3) Analyzing QC/QA data from the demonstration project to evaluate the performance of the IC roller with regard to its ability to ensure quality compaction.
4) Analyzing construction cost data and accounting for both training expenses and regularly anticipated IC costs after training.

Recommendations

5) Begin a monitoring program of the pavement section where the demonstration project took place to obtain changes in pavement performance relative to conventionally compacted sections.
6) Prepare subsequent demonstration projects to confer with results from the first demonstration project and to test for other applications of IC.
7) Draft QC/QA standards for adoption by public agencies to promote the use of IC by contractors if the demonstration projects prove that IC generates a net benefit.

Publications

- Technical Report and Project Brief: (http://www.ugpti.org/resources/reports/details.php?id=789)
- Journal Paper (Transportation Geotechnics): (http://www.sciencedirect.com/science/article/pii/S2214391216300368)

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Thank You

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