Electrically Conductive Heated Pavement System Webinar

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AASHTO Innovation Initiative

Zoom Meeting Platform User Information

- Participants are currently muted.
- A Question and Answer Session will follow presentations.
- Use Zoom Q & A button to ask questions at any time during the presentations.
- The meeting is being recorded and will be shared on the AII website at aii.transportation.org.

AASHTO
Innovation Initiative

Agenda

1. Overview of AII Program
2. Introduction and Overview of Improved Project Delivery Using GIS and Advanced Survey
3. Speaker Introductions
4. Caltrans Perspective
5. Colorado Department of Transportation Perspective
6. Michigan Department of Transportation Perspective
7. Key Takeaways and National Survey Results
8. Question and Answer Session with Panel


AASHTO
Technical Service Programs
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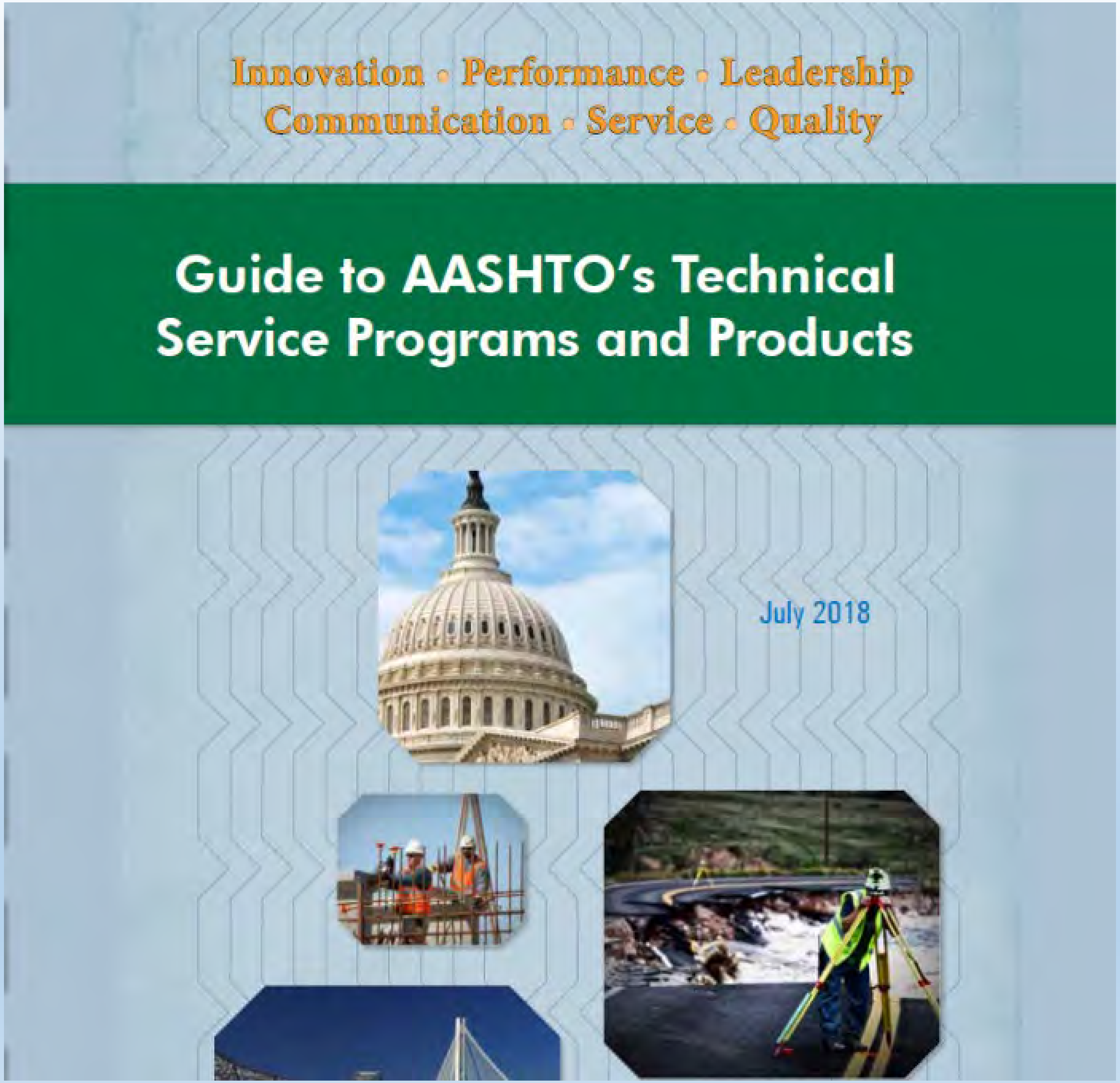
AASHTO SAFETY MANAGEMENT
AASHTO PERFORMANCE MANAGEMENT
AASHTO SAFETY HARDWARE MANAGEMENT
AASHTO TRANSIT MANAGEMENT
AASHTO RAIL MANAGEMENT
AASHTO ENVIRONMENTAL MANAGEMENT
AASHTO AASHTOWare SOLUTIONS
AASHTO RADIO FREQUENCY SOLUTIONS
AASHTO PRODUCT EVALUATION & AUDIT SOLUTIONS
AASHTO TECHNICAL TRAINING SOLUTIONS
AASHTO STEM OUTREACH SOLUTIONS
AASHTO CENSUS TRANSPORTATION SOLUTIONS



AASHTO Innovation Initiative (A.I.I.)

AASHTO Re:source

AASHTOWare

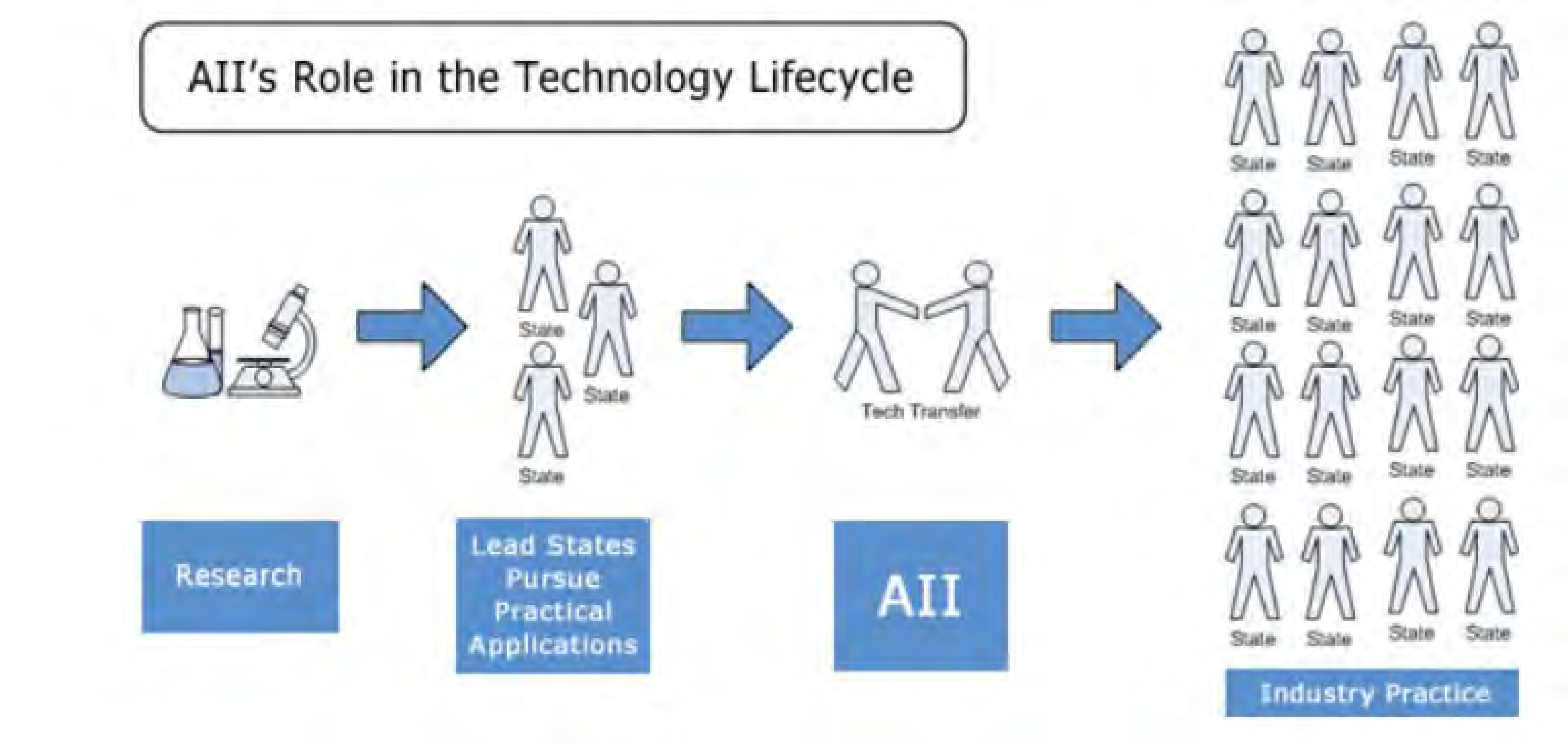
National Transportation Product Evaluation Program (NTPEP)

Development AASHTO Materials Specifications (DAMS)

All about AII – *The AASHTO Innovation Initiative*

- Established in 1999 & Operating since 2000
- Previously called the *Technology Implementation Group (TIG)*
- Facilitate the implementation of **high-payoff**, **ready-to-use**, **innovative technologies**
  - Focus Technologies
  - Additionally Selected Technologies

Support the implementation of 100+ technologies since 2001


AII's Role in the Technology Lifecycle
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Tech Transfer
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Research
Lead States Pursue Practical Applications
AII
Industry Practice

Current Active Focus Technologies

- Saw Cut Vertical Curb
- Freight Operations eXchange
- Hydrogen Fuel Cell Technology
- Electrically Conductive Concrete Heated Pavement System
- Steel Press Brake Formed Tub Girder
- Improved Project Delivery Using GIS
- Wrong Way Driving Systemic Approach
- Laser Ablation Coating Remove
- Beam End Repair with Ultra High Performance Concrete

AASHTO Innovation Initiative (AII)

What is AII?

Formerly the AASHTO Technology Implementation Group, AII advances innovation from the grassroots up: by agencies, for agencies, peer-to-peer.
More >>

Active Focus Technologies | Previous Focus Technologies | Additional Technologies
Nominate a Technology | Contact Us

Submit Your Nomination Today!

Active Lead States Teams Focus Technologies

- Saw Cut Vertical Curb
- Steel Press-Brake-Formed Tub Girder
- Beam End Repair Using Ultra-High Performance Conc
- Improved Project Delivery with GIS & Surveying
- Laser Ablation Coating Removal
- Systemic Approach to Wrong Way Driver Safety
- Electrically Conductive Concrete (ECON) Heated Pave

Resources

- NBC News Story - Heated Runways Help Prevent A
- Iowa DOT Research Solutions - Electrically Conduc
- Iowa DOT Research Summary Report - Self-Heatin
- Iowa State University - Self-Heating Electrically Co

Contacts

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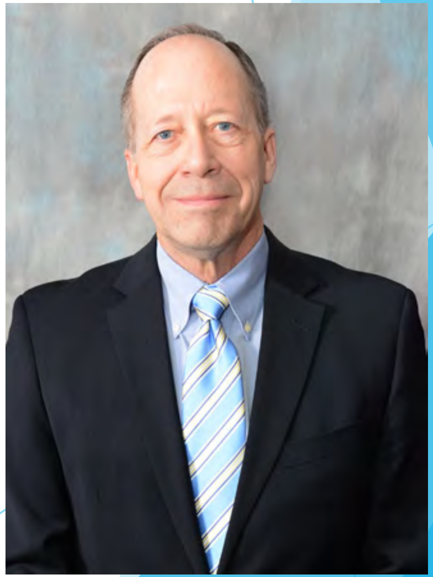
Expert Panel

Halil Ceylan

Vanessa Goetz

Ron Knoche



Bob Younie

Participant Poll #1

Electrically Conductive Concrete (ECON) Heated Pavement System (HPS): Overview

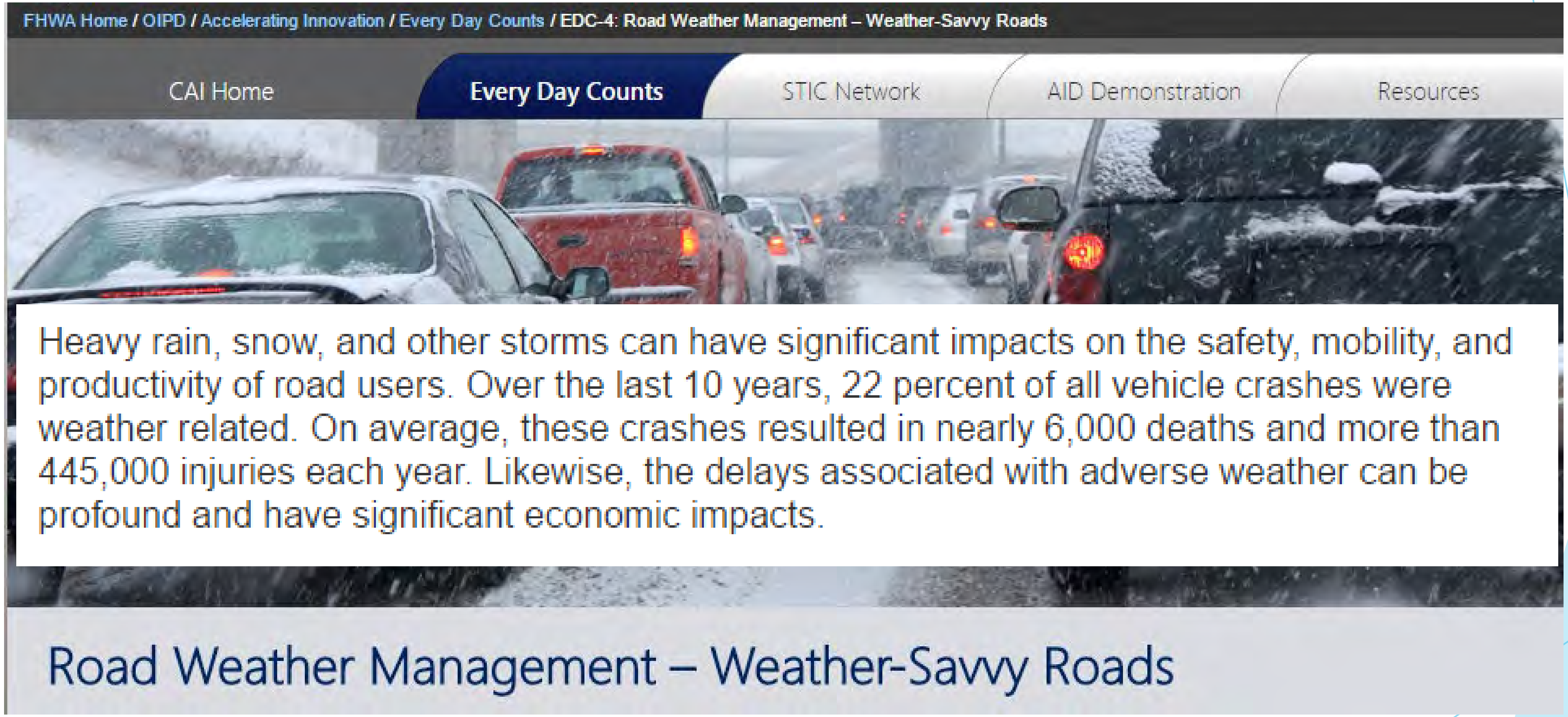
Acknowledgments/Credits/Acronyms

- Acknowledgments
  - Federal Aviation Administration (FAA) Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) Center of Excellence for General Aviation
  - Iowa Department of Transportation (Iowa DOT)
  - Iowa Highway Research Board (IHRB)
- Credits
  - More than 10 faculty and staff members and more than 20 graduate/undergraduate students involved
- Acronyms
  - HPS: Heated Pavement System
  - ECON: Electrically Conductive Concrete
  - PCC: Portland Cement Concrete

Outline

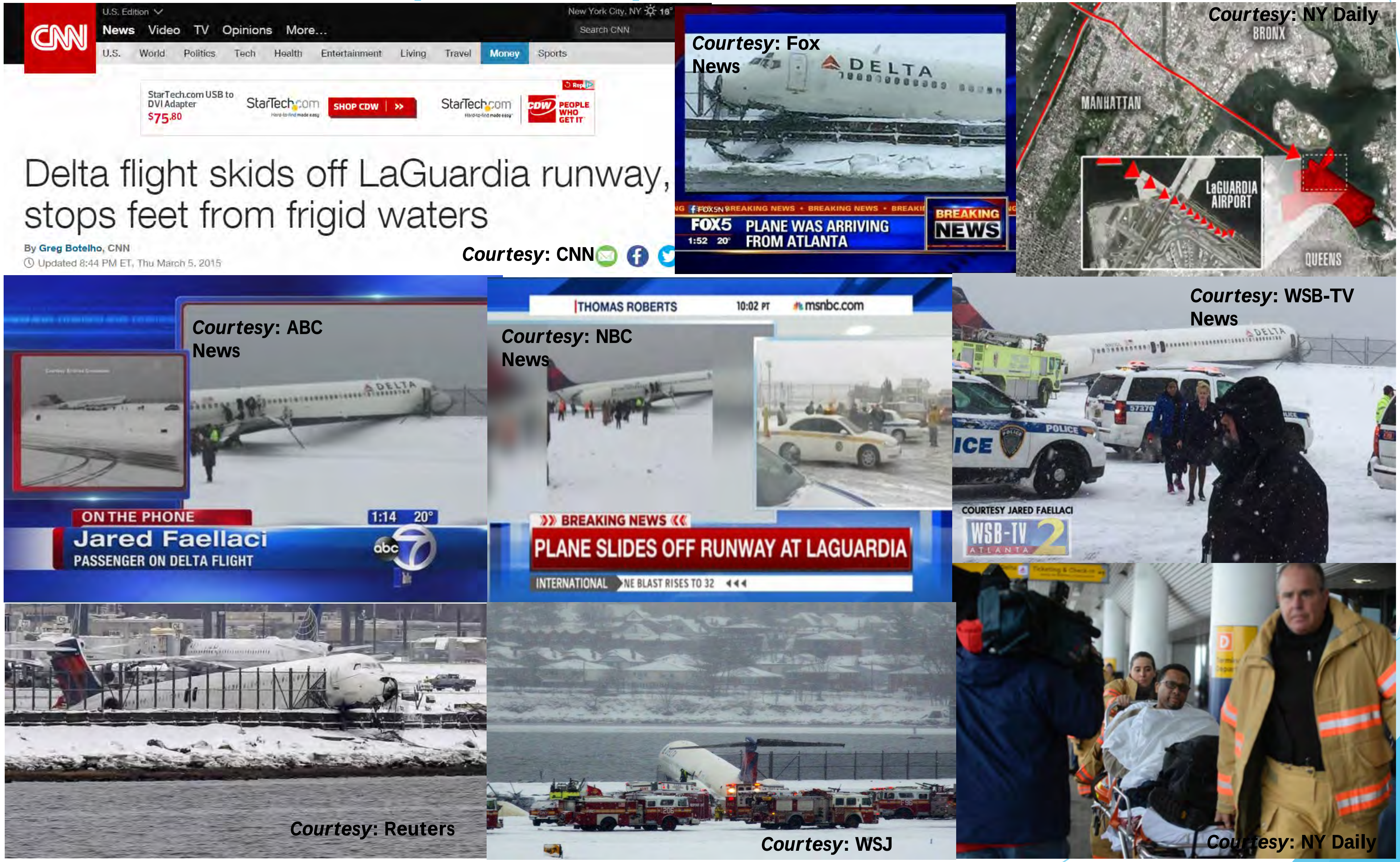
- Motivation
- Heated Pavement Technology
- ECON: Components
- ECON HPS: Components
- ECON HPS: Uses
- ECON HPS: Benefits
- ECON HPS: Construction Cost
- ECON HPS: Operation Cost
- Life-Cycle Cost Analysis (LCCA)

Motivation



(https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/roadweather.cfm)

Motivation (Cont’d)



Heated Pavement Technology

- Alternative solution to traditional snow and ice removal strategy
- Heating pavements from within the pavement structure can be accomplished by
  - Hydronic Heated Pavements: circulating warm fluids through pipes or tubes
  - Electrically Heated Pavements: passing electric current

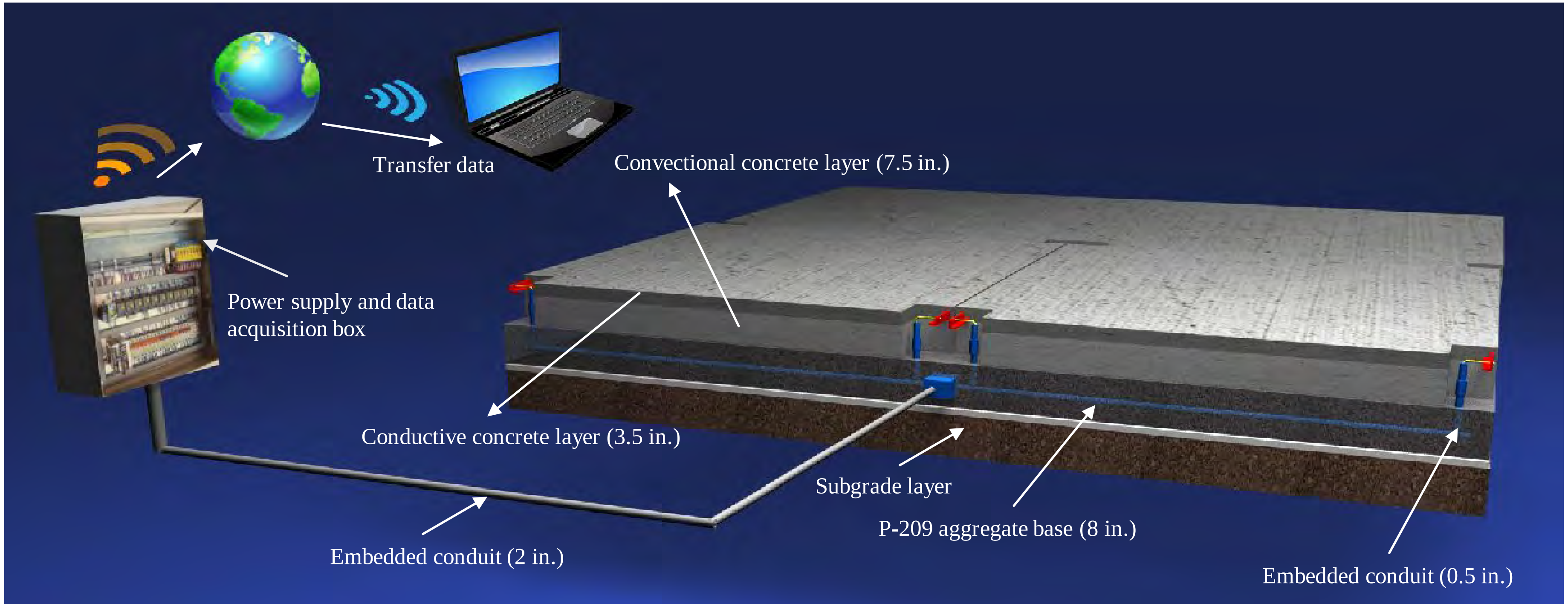
ECON: Components

- ECON, by virtue of its lower electrical resistivity compared to that of conventional Portland cement concrete (PCC), behaves like a resistive heating element

- Basic components of ECON
  - Portland cement
  - Aggregate (rock, sand, or gravel)
  - Water
  - Carbon fibers as conductive materials
  - Other components (if applicable): admixtures, supplementary cementing materials (SCMs), and so on

Electrically Conductive Concrete (ECON)

ECON HPS: Components



Power supply and data acquisition box consist of :

- Power meter (current and voltage monitoring unit)
- Step up transformer
- Relays
- Temperature sensing unit
- Power-switching on/off unit

ECON HPS: Uses

- Airport gate and apron areas
  - ECON HPS was implemented in the apron area of DSM International Airport
  - FAA PEGASAS Project 01 “Heated Airport Pavements” (https://www.pegasas.aero/projects/heated-airport-pavements)
- Roadways
  - ECON HPS was implemented near the central receiving area of Iowa DOT (experience significant amount of truck traffic)
  - IHRB/Iowa DOT Project “Self-Heating Electrically Conductive Concrete Demonstration Project” (https://prosper.intrans.iastate.edu/research/completed/self-heating-electrically-conductive-concrete-demonstration-project/)

ECON HPS: Uses (Cont'd)

- Sidewalks
  - ECON HPS will be implemented in constructing sidewalk of the city of Iowa City
  - IHRB/Iowa DOT Project "Implementing a Self-Heating, Electrically Conductive Concrete Heated Pavement System for the Bus Stop Enhancement Project in the City of Iowa City" (https://prosper.intrans.iastate.edu/research/in-progress/implementing-a-self-heating-electrically-conductive-concrete-heated-pavement-system-for-the-bus-stop-enhancement-project-in-the-city-of-iowa-city/)
- Bridge deck overlay, Highway rest areas and parking lots

ECON HPS: Benefits

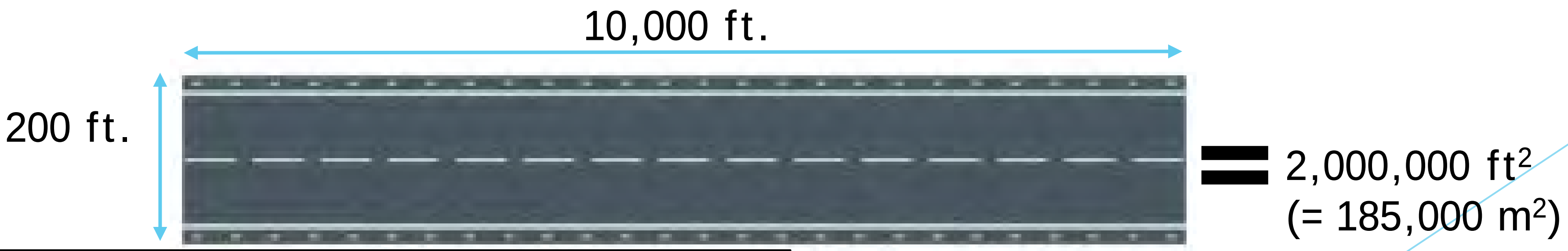
ECON HPS: Benefits (Cont'd)

- Safety Benefits
  - Reduces skidding, sliding, and slipping by vehicles from the removal of snow and ice
  - Reduces slip-and-fall incidents by pedestrians and associated lawsuits
  - Advances the mission of the Americans with Disabilities Act to ease the commute conditions of individuals with disabilities by mitigating hardship associated with snow and ice (e.g., on parking lots and ramps)
- Cost and Time Benefits
  - Reduces labor required to monitor winter ground conditions and operated snow/ice removal/treatment equipment by automating winter maintenance operations
  - Reduces material costs of de-icing chemicals and sand
  - Reduces capital and maintenance costs of heavy snow removal equipment
  - Increases the life span of fixtures and pavements by reducing erosion and damage that result from traditional methods
- Environmental Benefits
  - Reduces use of chemicals that can potentially harm the environment
  - Reduces carbon dioxide emissions from operation of snowplow equipment

ECON HPS: Construction Cost

- Cost estimation for typical gate area (3,000 yd^2 = 27,000 ft^2 = 2,500 m^2)
  - Regular PCC pavement construction cost ≈ 0.68 Million USD
  - ECON HPS construction cost: ≈ 1.08 Million USD

- Cost estimation for typical runway area(222,000 yd^2 = 2,000,000 ft^2 = 185,000 m^2)
  - Regular PCC pavement construction cost ≈ 70 Million USD
  - ECON HPS construction cost: ≈ 105 Million USD



Note: 1yd^2 = 9 ft^2 = 0.83 m^2

ECON HPS: Operation Cost

Max. current (when snow stopped at 12:30pm)	Min. current (when system was turned on)	Average current	Voltage
33 (A)	25 (A)	29 (A)	200 (V)

Average power	Area of slab (15 ft. × 12.5 ft.)	Average power per unit area
5,800 (W)	21 (yd^2) = 17.4 (m^2)	~280 (W/yd^2) = ~333 (W/m^2)

If the system runs for 7 hrs.,

- Energy consumed: 0.28 kW/yd^2 × 7 hrs. = 2.0 kWh/yd^2 (= 2.3 kWh/m^2)
- Cost: 2.0 kWh/yd^2 × ¢8.0/kWh = ~¢16/yd^2 (= ¢19/m^2)

Life-Cycle Cost Analysis (LCCA)

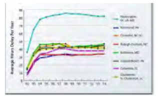
Data collection

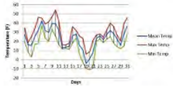
Construction and actual operation measurements from DSM airport

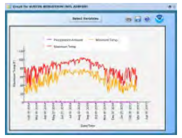
RSMeans FROM THE GORDIAN GROUP

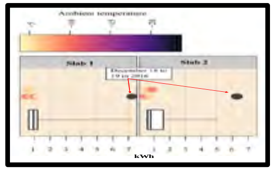
Publically available data

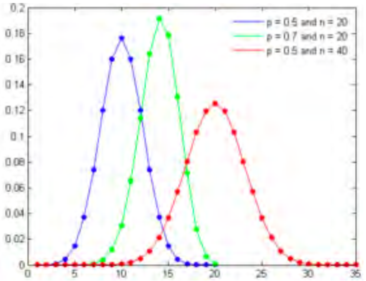
Data analysis



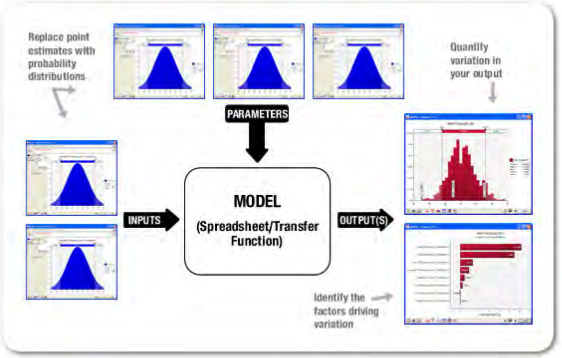




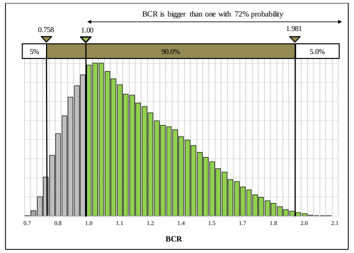




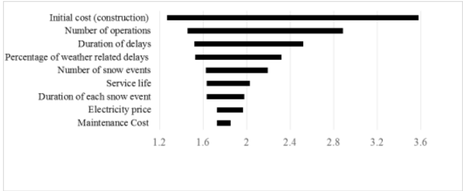
Developing LCCA framework



Monte Carlo simulation based Life cycle cost analysis framework

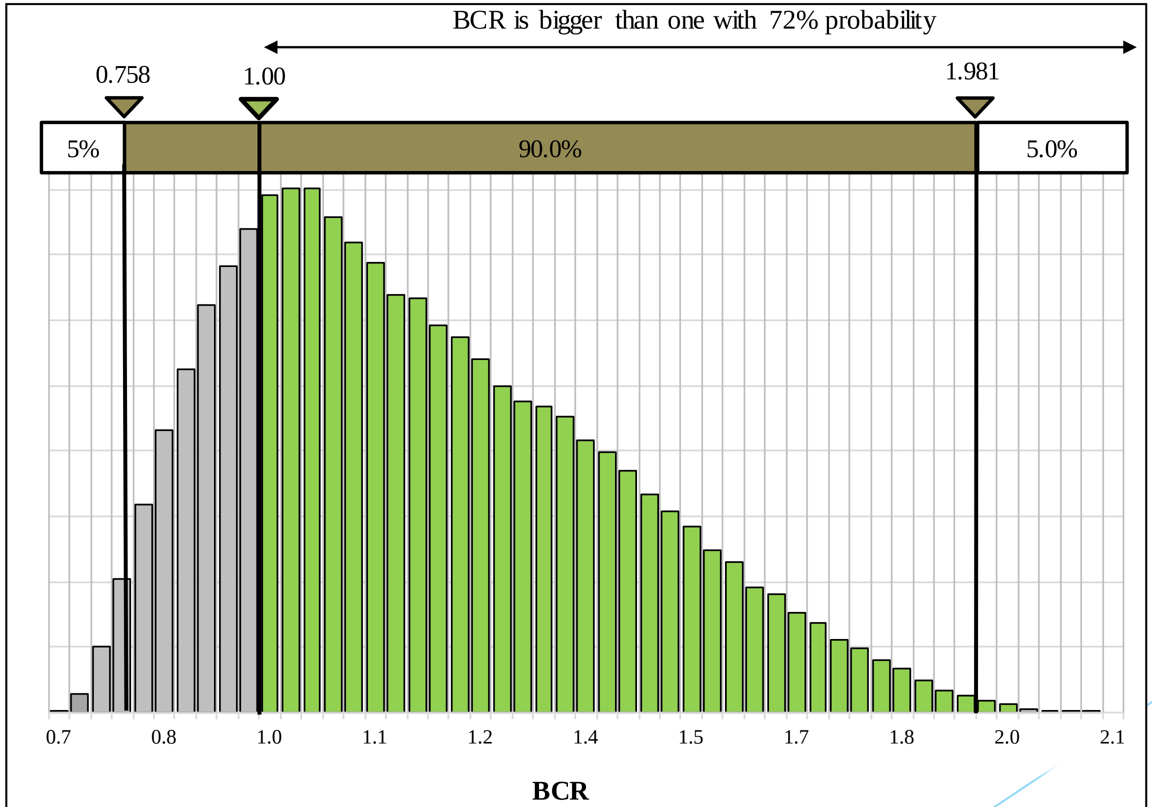


Stochastic sensitivity analysis



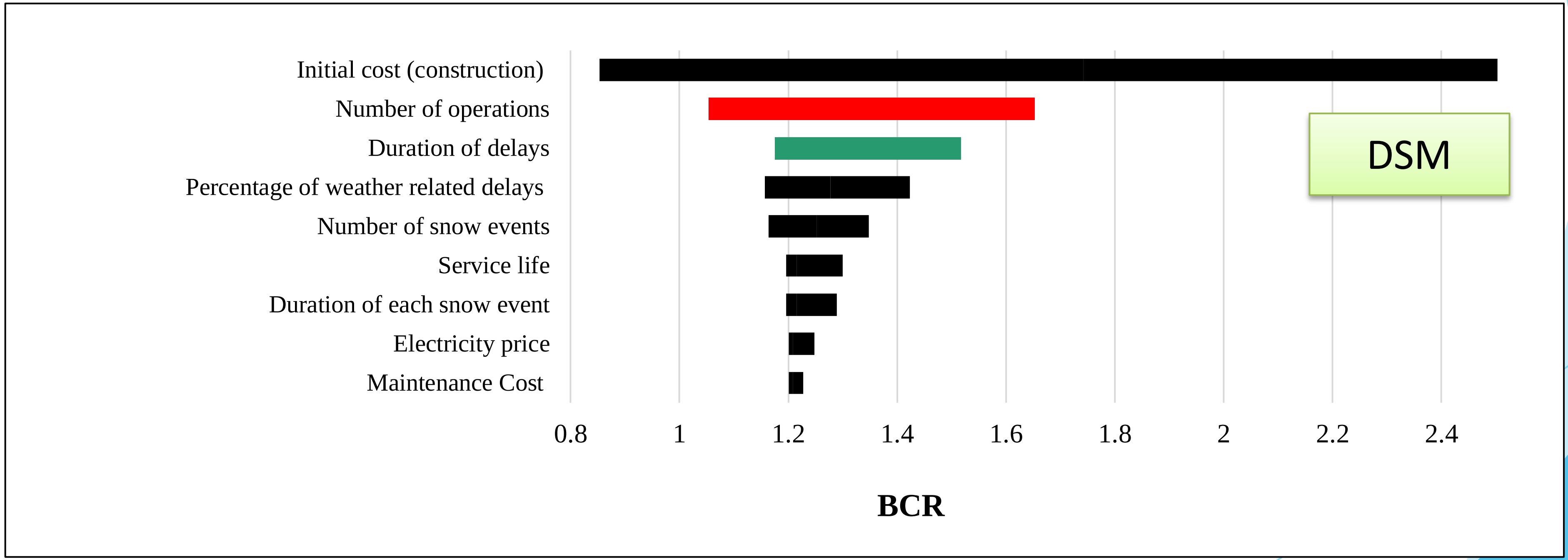
LCCA (Cont’d)

- Monte Carlo simulation (MCS) probability density function results for benefit cost ratio (BCR) when ECON HSP would be implemented in over the entire apron area at Des Moines International Airport (DSM)



LCCA (Cont'd)

- Sensitivity analysis results showing the actual impact of input variables on the overall BCR



ECON HPS in Detail: System Examples

Outline

- ECON Mixture
- Electrode Configuration
- ECON HPS Design
- Autonomous/Automated Control System
- ECON HPS Construction
- Electrical Safety
- Radio Frequency Interference

ECON Mixture

Air-Entraining

Water-Reducer

Corrosion Inhibitor

Viscosity-Modifying

ECON

Admixtures
(If applicable)

Cementitious Matrix
(Similar to plain concrete)

Aggregates
(Similar to plain concrete)

Conductive Phase
(Carbon fiber)

SCMs

Portland Cement

Fine Aggregate

Coarse Aggregate

Carbon Fiber

ECON Mixture (Cont'd)

Item	DSM Airport SSD Weights (lb./yd³)	Iowa DOT SSD Weights (lb./yd³)	Iowa City SSD Weights (lb./yd³)
W/CM	0.42	0.42	0.42
Cementitious content	**800**	**795**	**900**
Cement	800	633	900
Fly Ash (type C)	-	162	-
Coarse Aggregate	1,001	986	1,270
Fine Aggregate	1,134	1,079	1,050
Intermediate Aggregate	499	508	-
Water	337	337	380
Carbon Fiber	1.0 (% Vol.)	1.25 (% Vol.)	1.25 (% Vol.)

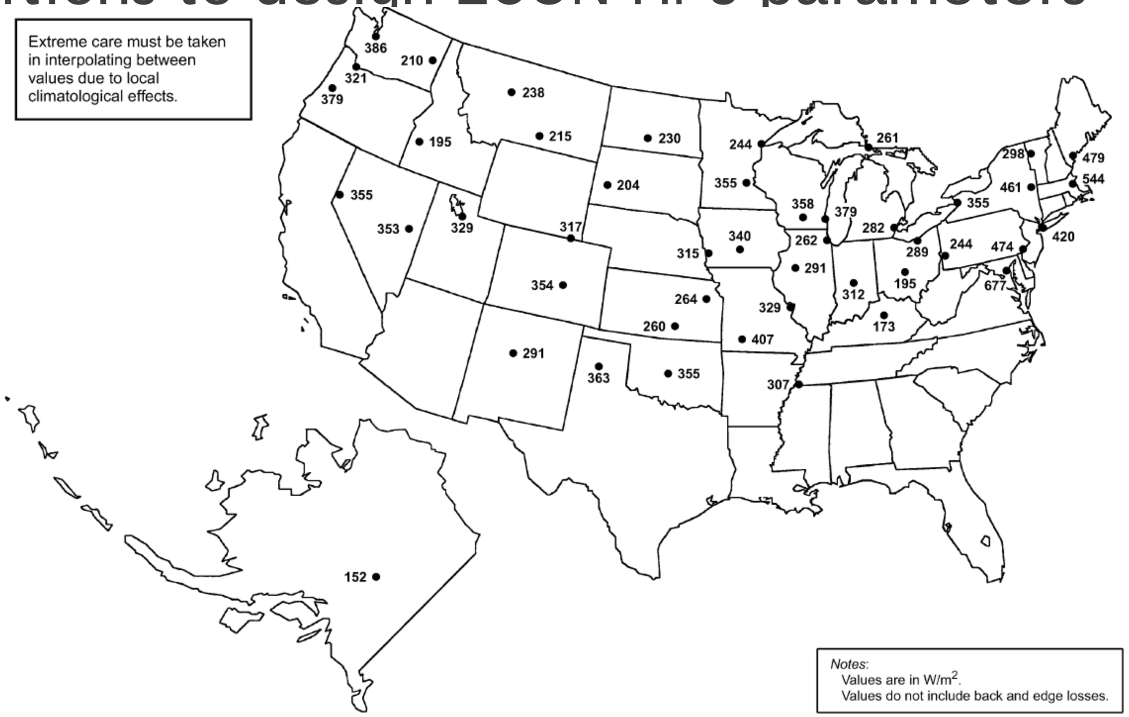
Electrode Configuration

- Stainless steel electrodes are preferred since it exhibits resistance to corroding
- The higher the electrode-concrete contact area (electrode size), the higher the temperature increase rate
- Neutral electrodes need to be placed next to all the joints between ECON HPS slabs

Items	DSM international airport	Iowa DOT parking lot
Material	Perforated stainless steel	Stainless steel
Size	3.81 cm ×3.81 cm ×0.32 cm	1.9 and 2.5 cm
Shape	Angle	Flat, circular solid, and circular hollow
Spacing (cm)	91.46	508, 648, and 914

ECON HPS Design

- Estimated energy density (W/yd²) for melting snow/ice based climatic conditions to design ECON HPS parameters
  - Rate of snowfall
  - Ambient temperature
  - Humidity
  - Wind speed

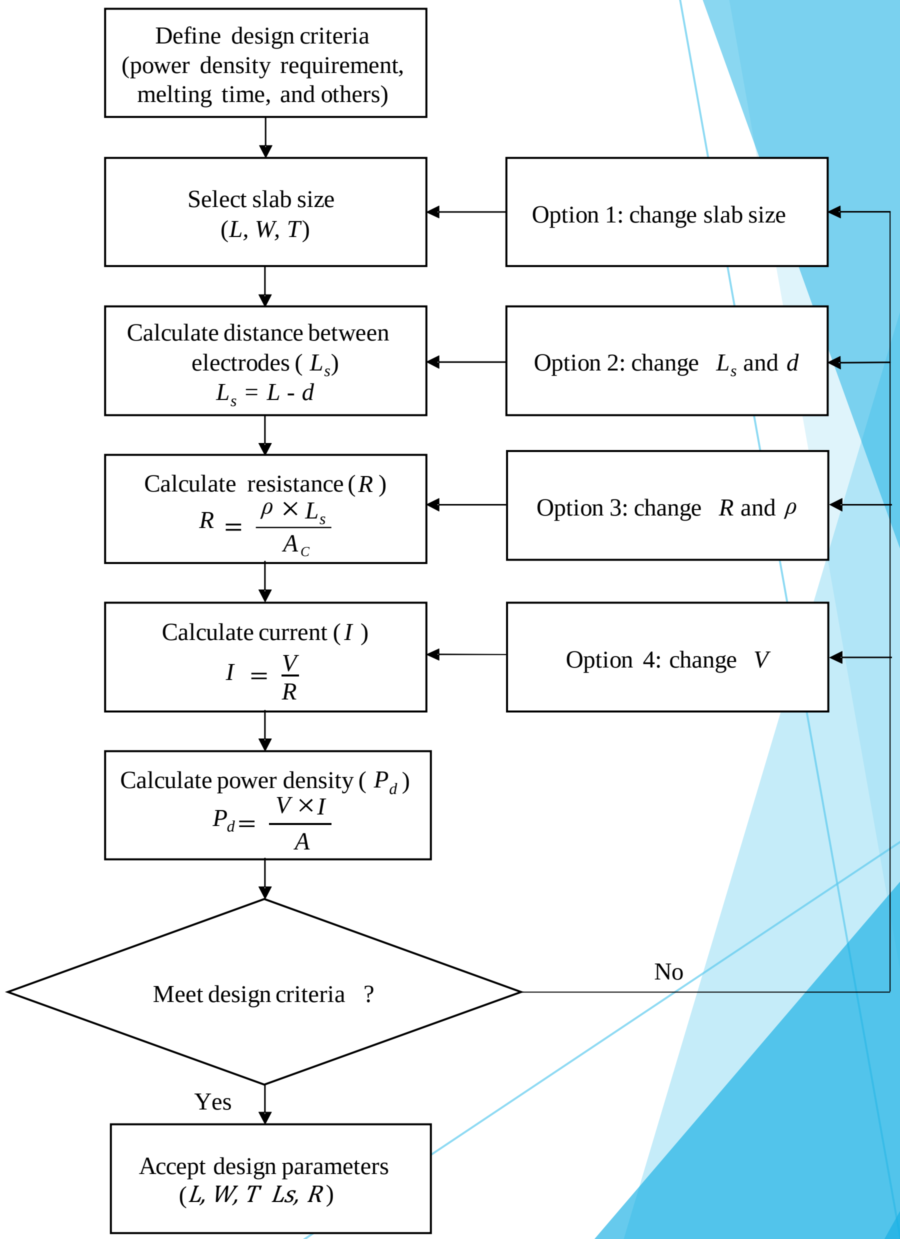


(ASHRAE 2015)

Note: 1 W/yd² = 1.2 W/m²

ECON HSP Design (Cont'd)

- To determine design parameters
  - Slab dimension:
    - *L: length*
    - *W: width*
    - *T: thickness*
  - Distance between electrodes: *Ls*
  - Electrical resistivity: *R*
  - Power required: *P*

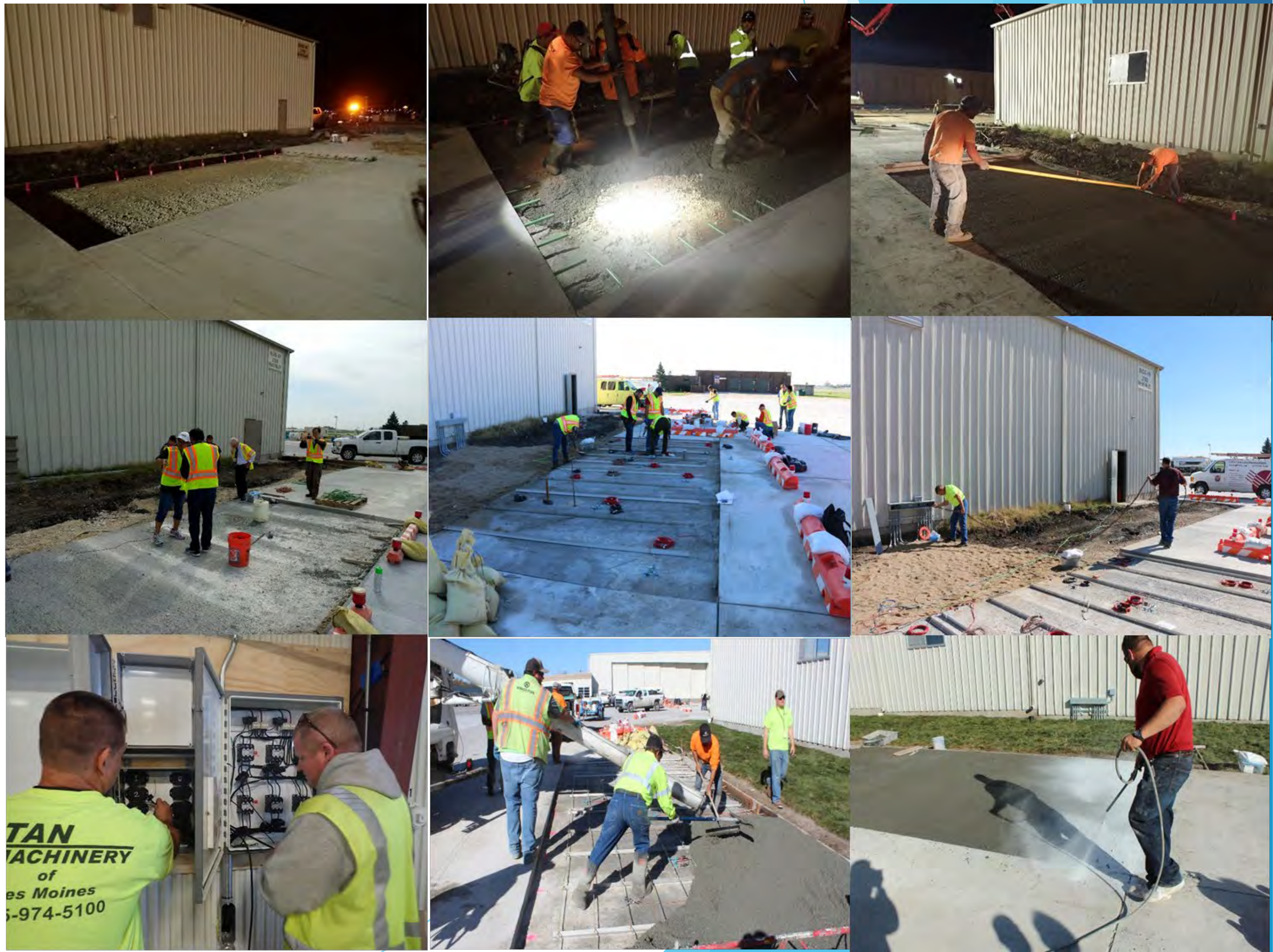


I: electric current
A_c: cross section parallel to the electrodes
ρ: electrical resistivity
d: distance between the slab edge to electrodes

Autonomous/Automated Control System

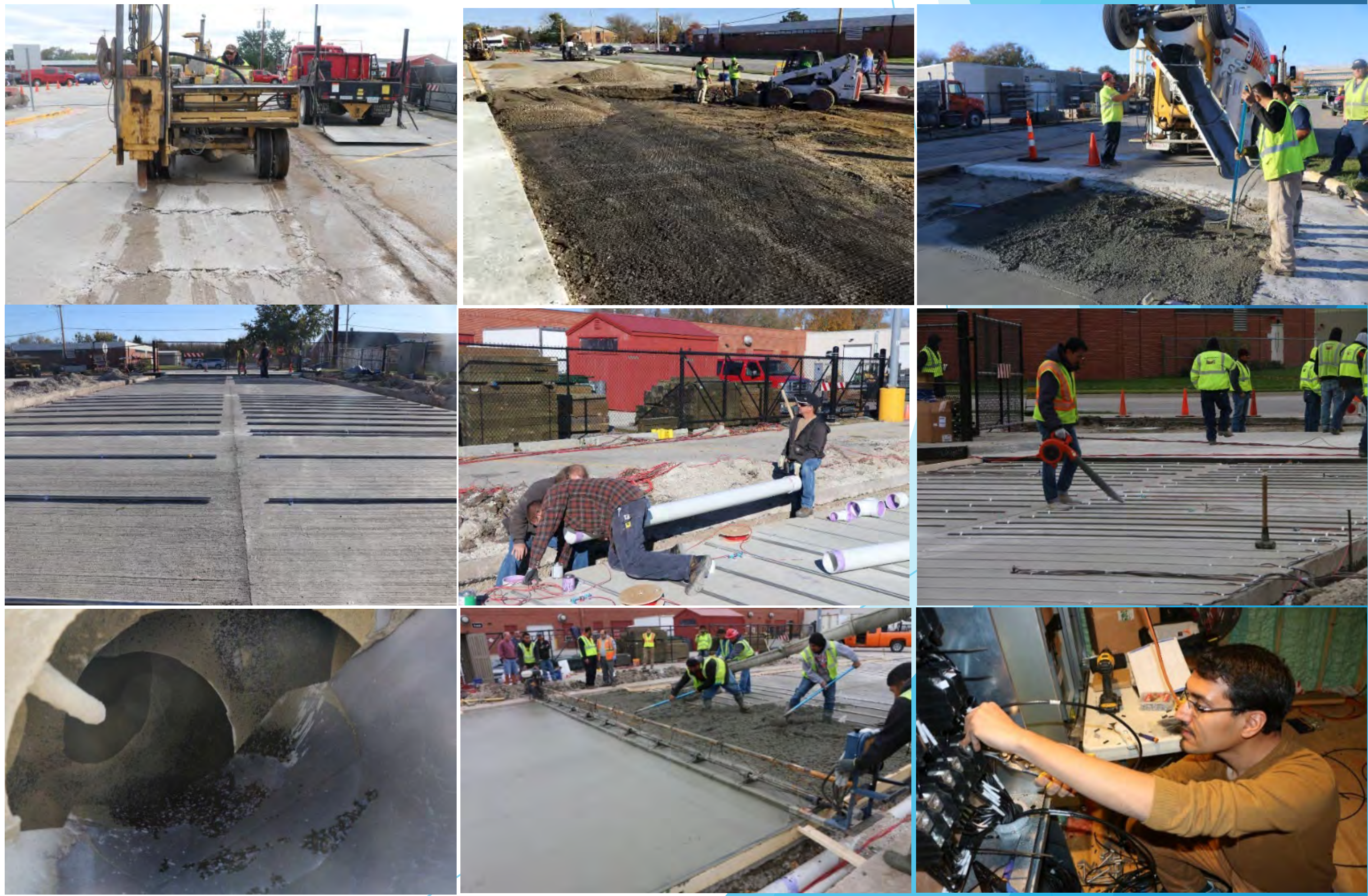
ECON HPS Construction

- DSM (November 2016)



ECON HPS Construction (Cont’d)

- Iowa DOT (October 2018)



Electrical Safety

- Electrical shock might occur if the current is of significant values and the human contact is creating a shorter path to ground
- Based on National Institute for Occupational Safety and Health, human health is at risk if **20 mA** goes to the heart

Table 1 Estimated effects of 60 Hz AC currents

Current	Effect
1 mA	Barely perceptible
16 mA	Maximum current an average man can grasp and "let go"
20 mA	Paralysis of respiratory muscles
100 mA	Ventricular fibrillation threshold
2 A	Cardiac standstill and internal organ damage
15/20 A	Common fuse breaker opens circuit

Electrical Safety (Cont’d)

- Field test study on surface current indicates ECON did not pose immediate health risk to human touch

Experiment	R1 (kΩ)	Content of wells	Salt bridge	Current (mA)	<20 mA
1	10	Dry	Absent	1.38	SAFE
2	10	Water	Absent	6.19	SAFE
3	10	Salt water (low conc.)	Absent	10.06	SAFE
4	10	Salt water (low conc.)	Present	8.70	SAFE
5	22	Water	Absent	3.90	SAFE
6	22	Salt water (low conc.)	Absent	4.20	SAFE
7	22	Salt water (low conc.)	Present	4.13	SAFE
8	22	Salt water (high conc.)	Present	3.87	SAFE


Experiment with Present of Salt Water

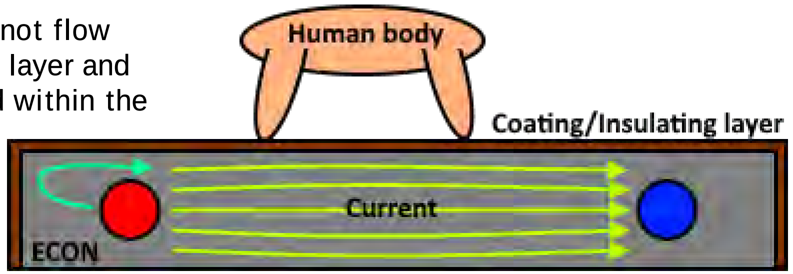

A pilot touching the DSM Slabs


NBC Today Show News Crew Warming Up

Electrical Safety (Cont'd)

- Another method of further improving the safety of ECON is by adding a thin layer of insulating barrier on the top surface

Current cannot flow through the layer and is contained within the slab



Human in contact will not be harm as well

Front cross-sectional view

Electrical Safety (Cont'd)

- 120 VAC was applied to all the samples and a conductive gel was used to more accurately measure the surface voltage
- Tnemec 297 finish coat showed on average 87% reduction in maximum surface current

One Layer of finish coat

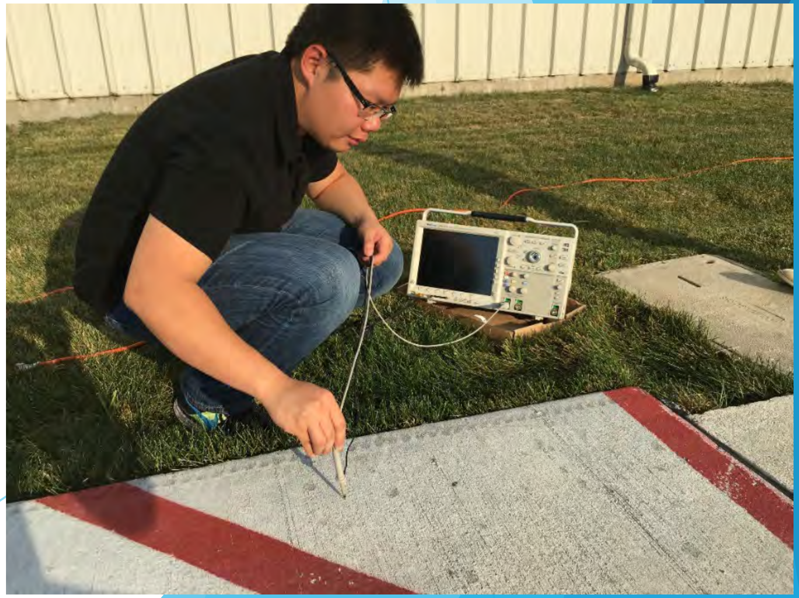
Specimen	Paint Names	Surface Current Without paint (mA)	Surface Current With paint (mA)	Percent Change
Beam	Tnemec 297 (finish coat)	0.41	0.08	-80%
Slab	Tnemec 297 (finish coat)	0.13	0.02	-84%

Two Layers of finish coat

Specimen	Paint Names	Surface Current Without paint (mA)	Surface Current With paint (mA)	Percent Change
Beam	Tnemec 297 (finish coat)	0.74	0.005	-99%
Slab	Tnemec 297 (finish coat)	0.35	0.04	-88%

Radio Frequency Interference

- To ensure ECON will not cause any radio frequency interferences such as disrupting the connection between transmitter and receiver, temporary loss of signal, declining quality of signal or preventing reception altogether, radio frequency interference test was conducted



Radio Frequency Interference (Cont’d)

Experiment	Number of Peaks Observed	Frequency of Highest Peak (Hz)	Amplitude of Highest Peak (dBm)
1	1	60	23.16
2	1	60	26.98
3	1	60	-8.044
4	1	60	15.89
5	1	60	27.94
6	1	60	32.68

- The research team is not concerned with the amplitude of the peaks especially at 60 Hz since this can be affected by other electrical appliances connected to the same power line

- The consistency of the results indicate strongly that HPS will not create radio frequency interference

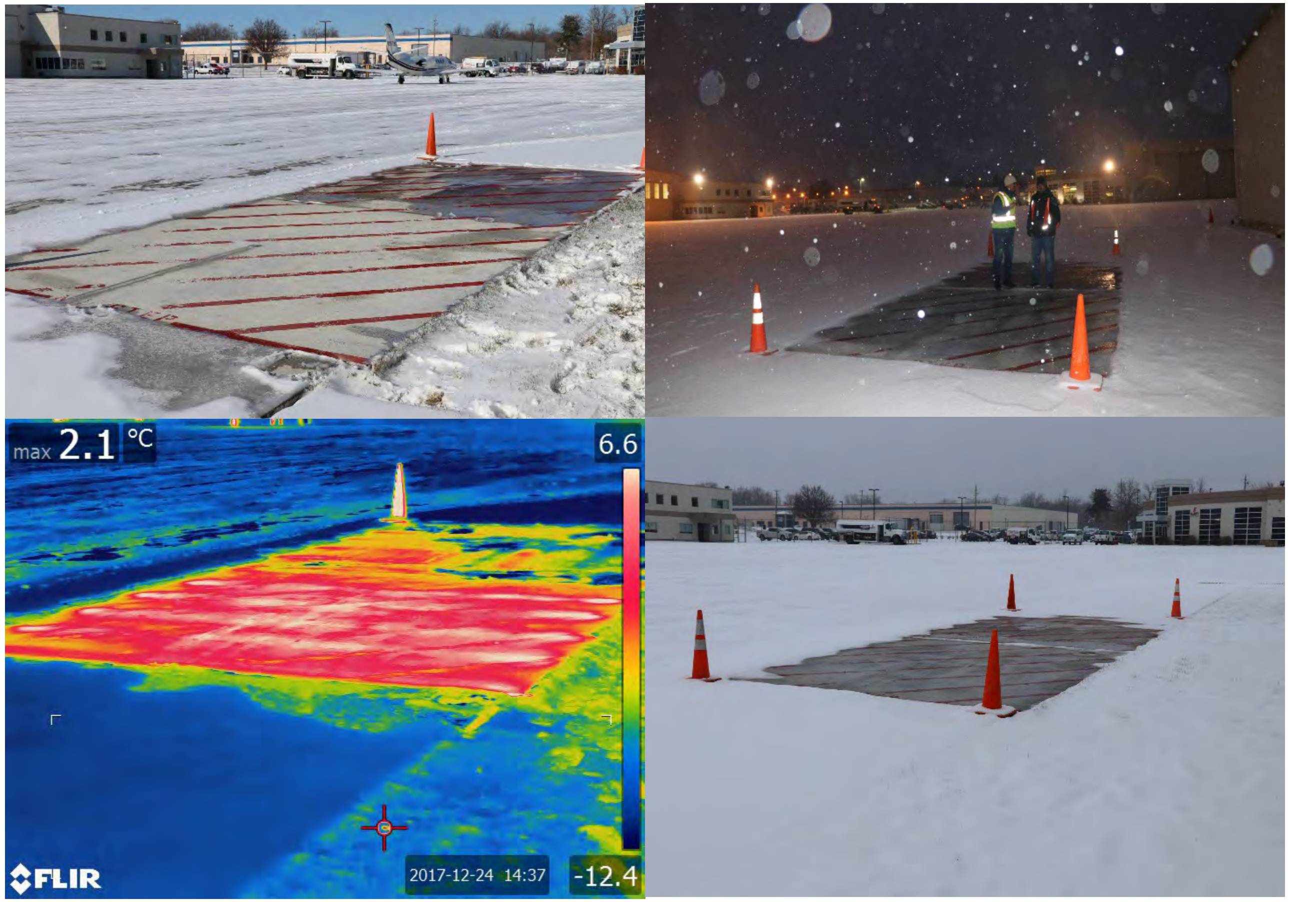
ECON HPS Performance

Outline

- DSM ECON HPS Performance: 1st Year (2016-2017)
- DSM ECON HPS Performance: 2nd Year (2017-2018)
- DSM ECON HPS Performance: 5th Year (2020-2021)
- DSM ECON HPS Performance: 7th Year (2022-2023)
- Iowa DOT ECON HPS Performance: 1st Year (2018-2019)
- Iowa DOT ECON HPS Performance: 2nd Year (2019-2020)
- Iowa DOT ECON HPS Performance: 3rd Year (2020-2021)
- Structural Evaluation

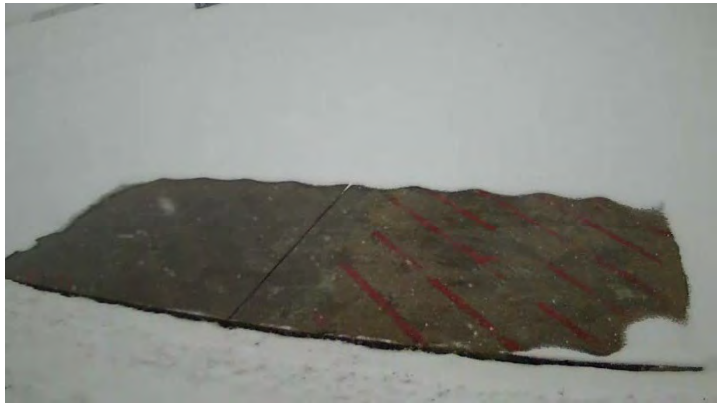
DSM ECON HPS Performance: 1st Year (2016-2017)

DSM ECON HPS Performance: 2nd Year (2017-2018)



DSM ECON HPS Performance: 5th Year (2020-2021)

Date	January 25-26, 2021
Snow thickness	10 in.
Operation time	24 hours
Mean temperature	23°F (-13.3°C)
Minimum temperature	19°F (-17.2°C)
Maximum temperature	25°F (-9.4°C)
Wind speed	22 mph
Average relative humidity	88%

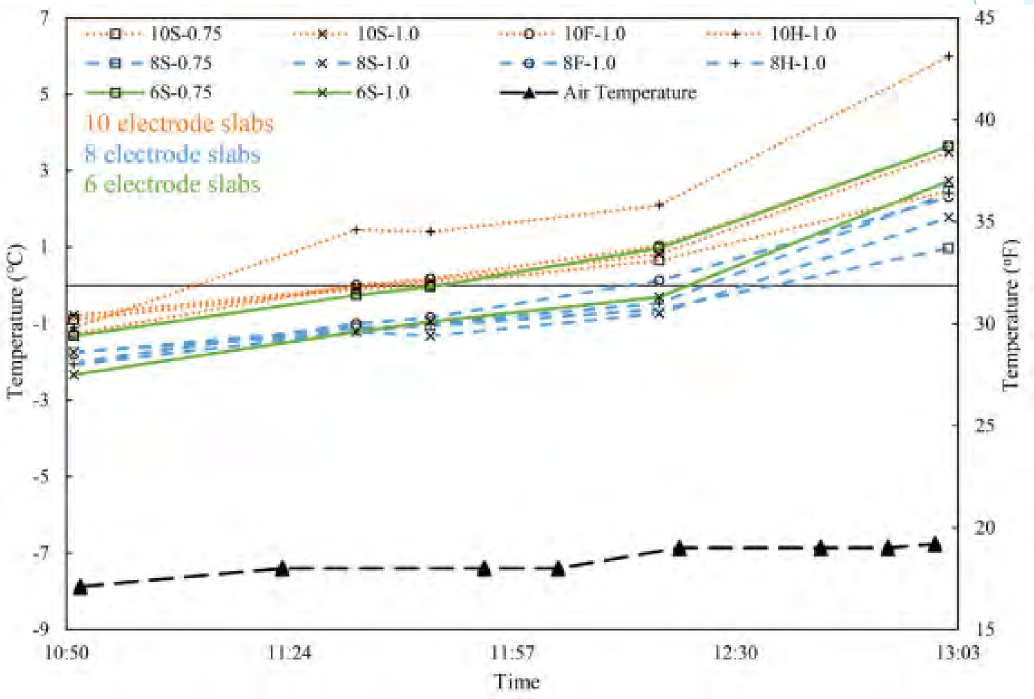


DSM ECON HPS Performance: 7th Year (2022-2023)

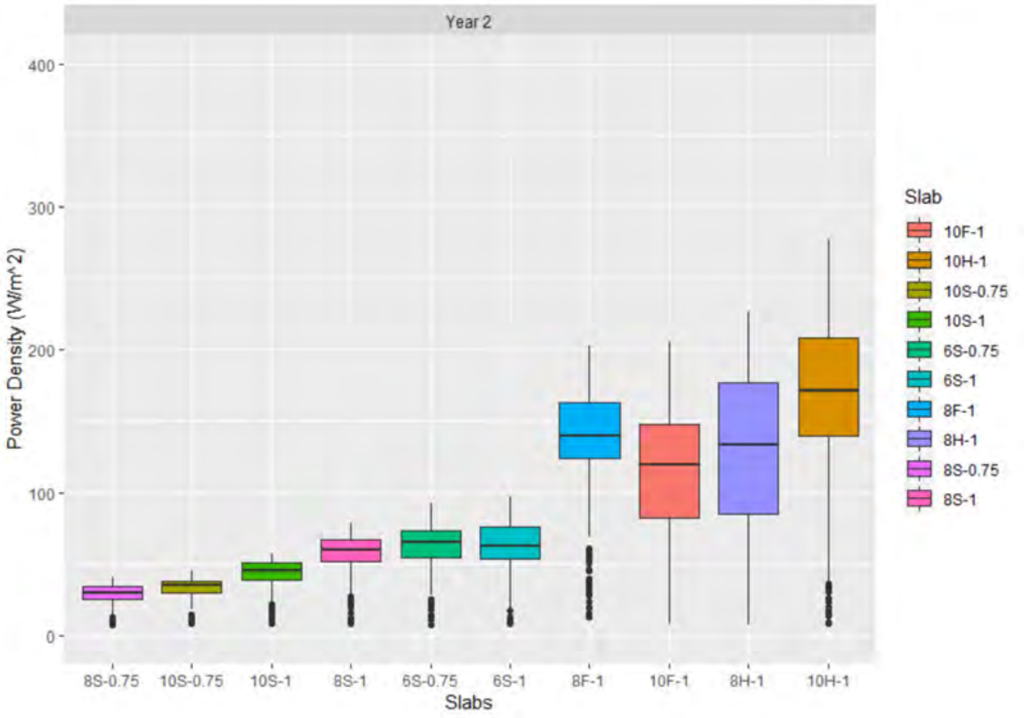
Date	January 18, 2023
Snow thickness	4 in.
Operation time	13 hours
Mean temperature	32°F
Wind speed	10 mph

Iowa DOT ECON HPS Performance: 1st Year (2018-2019)

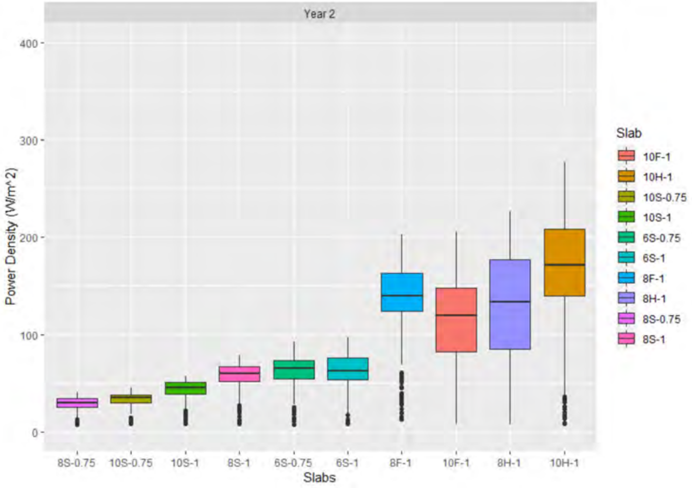
Date	February 19 to 20, 2019
Snow thickness	2.0 inch
Operation time	6 hours
Mean temperature	24°F (-4.4°C)
Wind speed	12 mph
Average relative humidity	86%

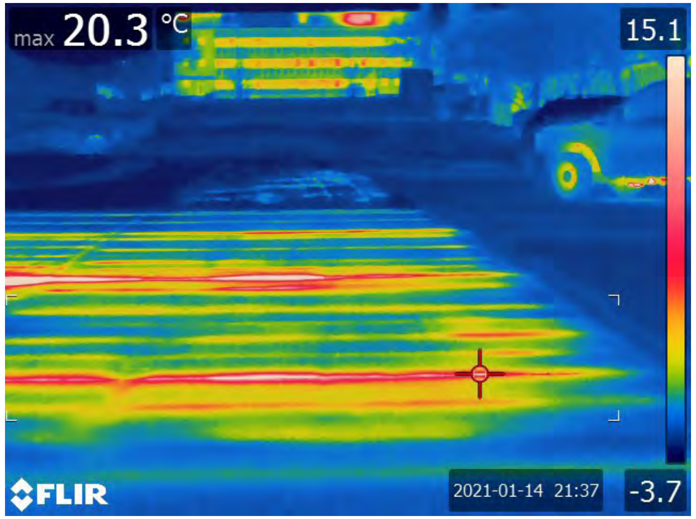


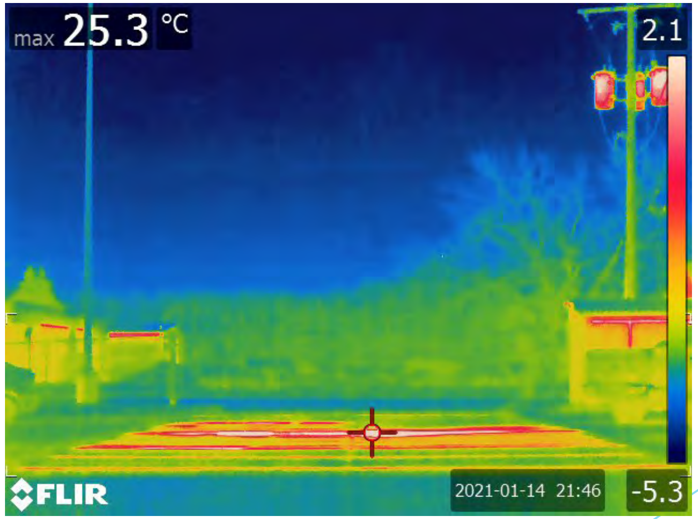
Iowa DOT ECON HPS Performance: 2nd Year (2019-2020)



Iowa DOT ECON HPS Performance: 3rd Year (2020-2021)

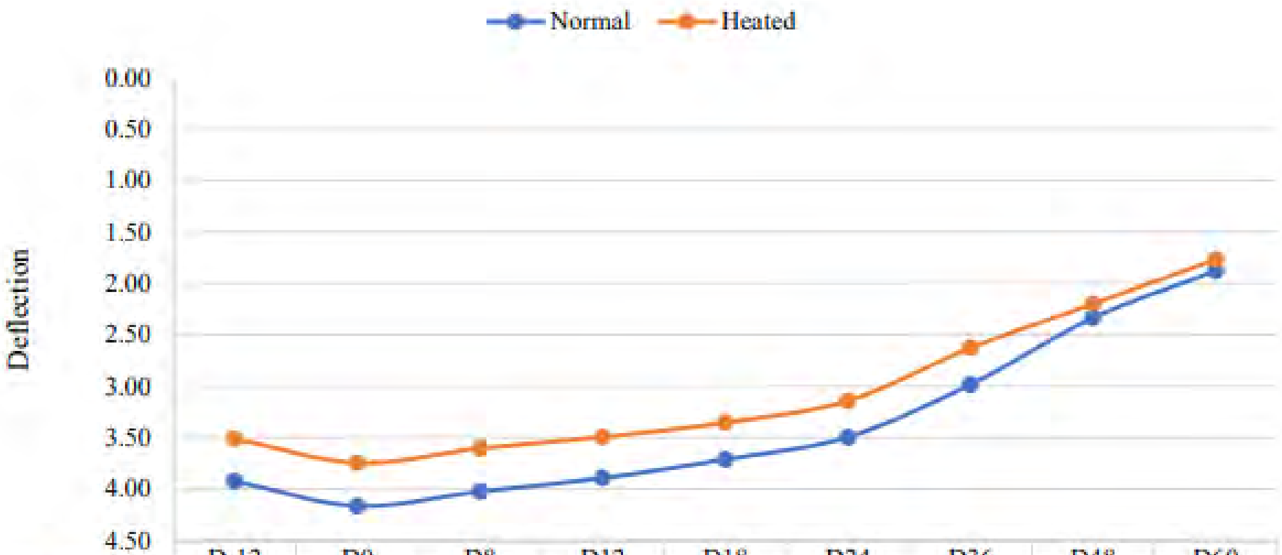






Structural Evaluation

- Falling Weight deflectometer (FWD) testing on Iowa DOT ECON HPS



	D-12	D0	D8	D12	D18	D24	D36	D48	D60
Normal	3.93	4.17	4.02	3.90	3.71	3.50	2.99	2.34	1.88
Heated	3.51	3.75	3.61	3.50	3.36	3.14	2.63	2.20	1.77

Structural Evaluation (Cont’d)

- ECON vs. Conventional PCC
  - In terms of performance: ECON is better than PCC
    - Strength: ECON is stronger than its equivalent PCC under compression, tension, and flexure
    - Durability: ECON has lower permeability than PCC which gives it higher durability and susceptibility to D-cracking
    - Shrinkage: ECON is less susceptible to drying shrinkage and plastic shrinkage cracking
    - Post-cracking behavior:
      - ECON shows higher post-cracking strength than PCC
      - The post-cracking permeability in ECON is lower than PCC
      - The post-cracking durability in ECON is higher than PCC
    - Fatigue: ECON has longer fatigue life than PCC

ECON HPS Implementation Considerations

Iowa City Muscatine Avenue Pedestrian Crossing Project

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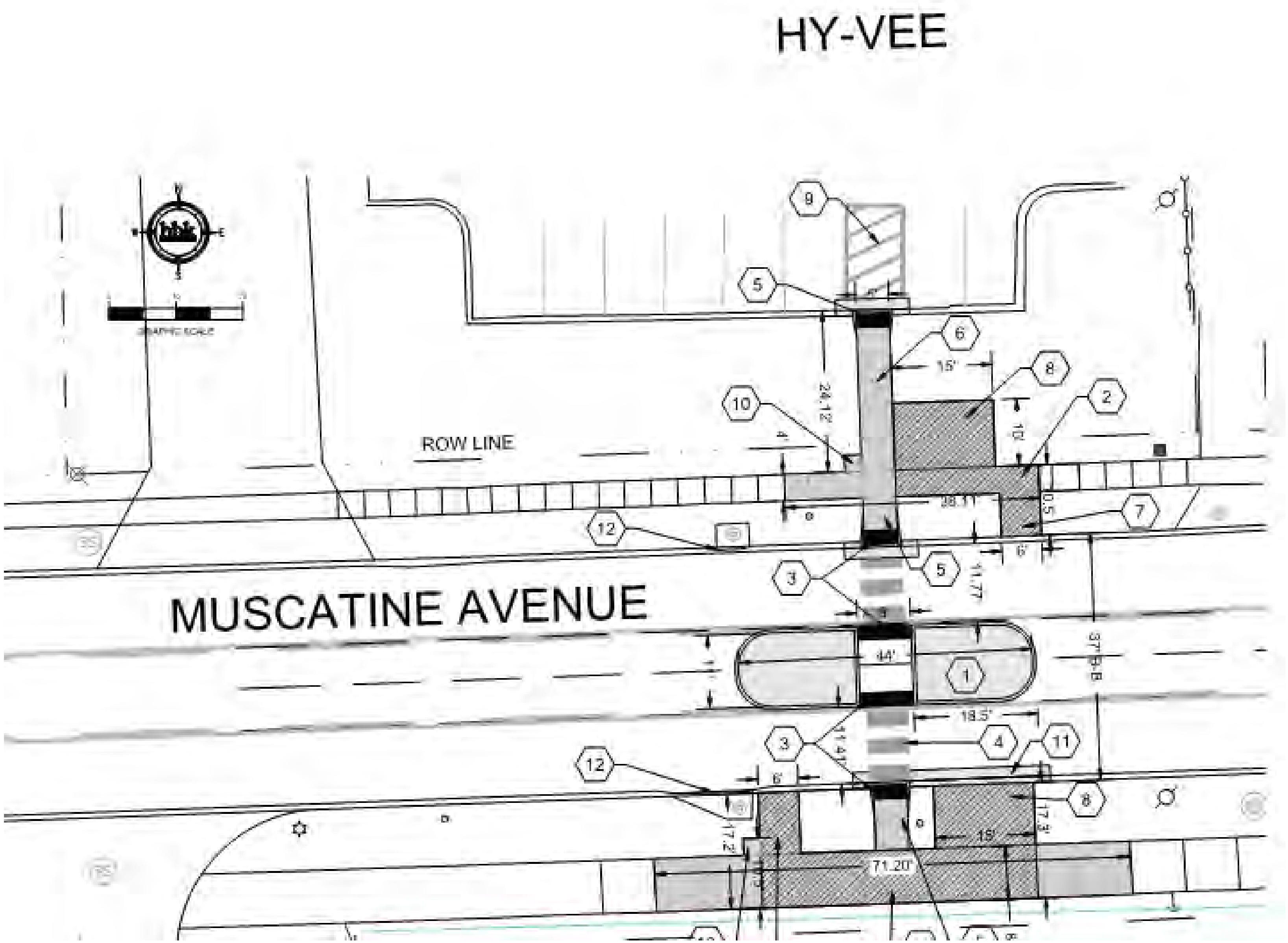
Project Development

- Location study was conducted by the Metropolitan Planning Organization of Johnson County
  - Indicated the need for a cross walk
  - Mid block location was ideal if coupled with a refuge island
  - Transit requested a bus shelter be added at the bus stop
- Iowa City hired a consultant to develop the plans
  - Original plan was to develop with traditional concrete
  - Iowa City indicated a desire to develop the project using electrically conductive concrete
  - Consultant worked with Iowa State University to develop the plans

Project Location



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Project Overview

Electrically Conductive Concrete (ECON)

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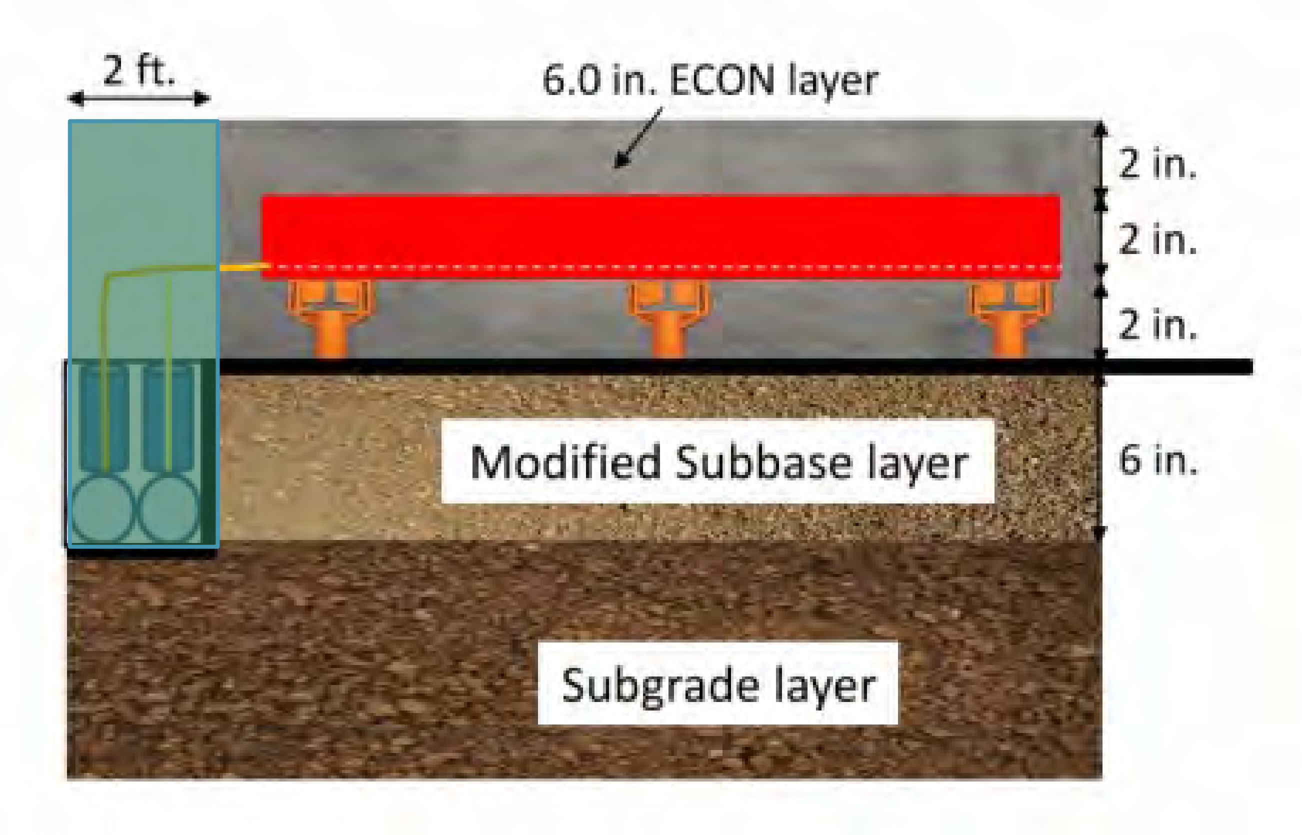

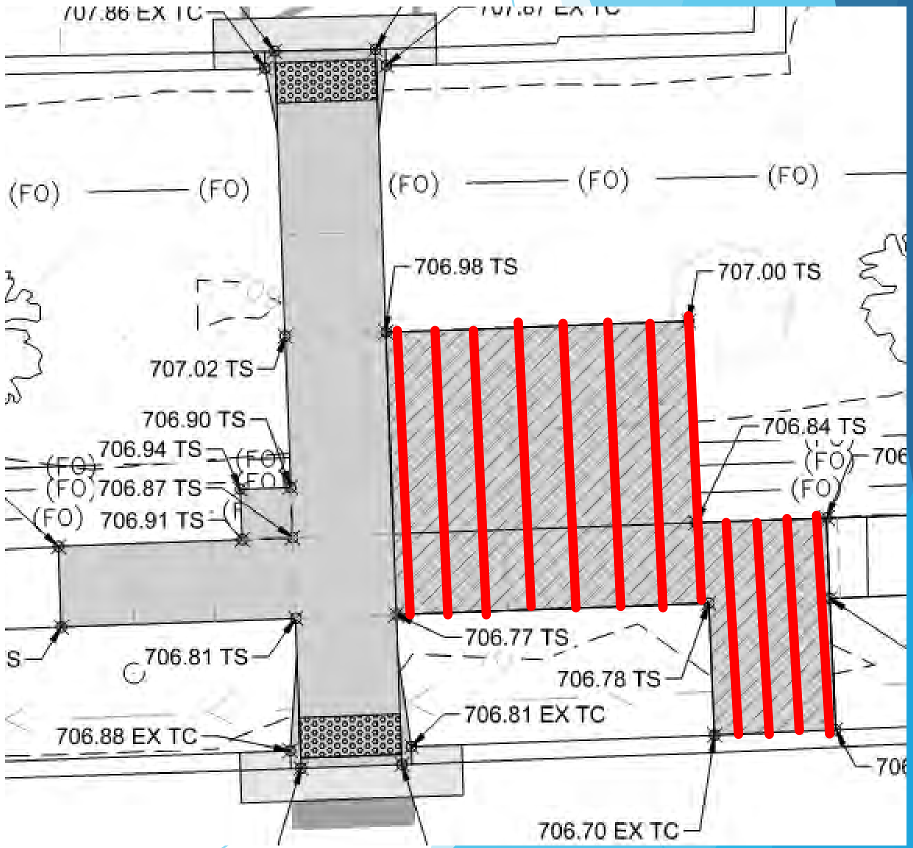

Electrically Conductive Concrete (ECON)

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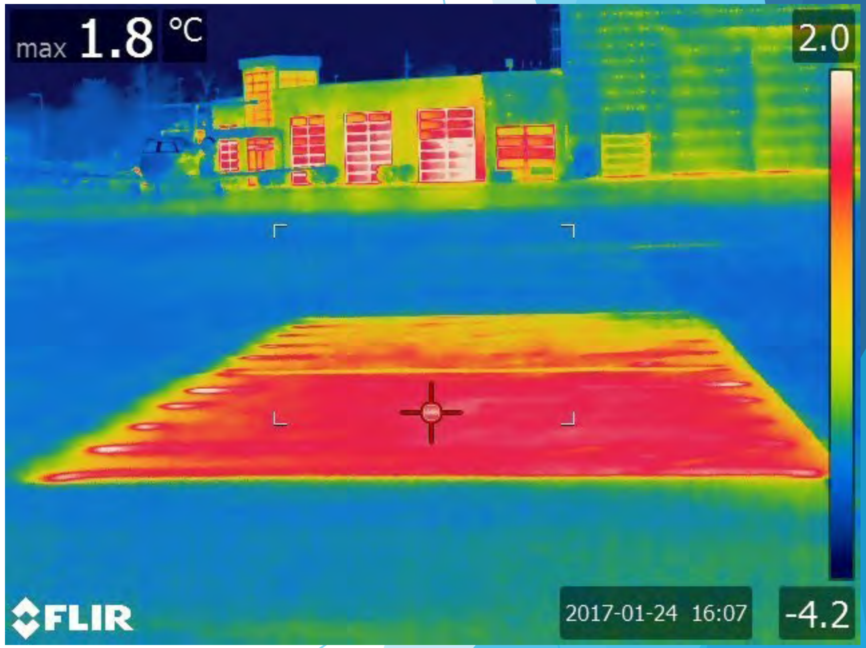

Project Budget

- Iowa City worked with the Iowa Highway Research Board to develop an implementation project
  - Iowa City committed to fund up to $90,000
  - Iowa Highway Research Board committed to the delta costs up to $20,000

Schedule

Bid Opening	September 14, 2021
Award Contract	September 21, 2021
Begin Construction	October 2021
Final Completion	June 2022

Costs

Estimated Construction Cost- $88,000.00 (ECON)

Actual Bid- $216,309 (ECON) $96,309 (Concrete)

Project Setback

- Bids and budget setback
  - Received three bids
  - ECON base bid significantly higher than estimate
  - Requested additional funding from the Iowa Highway Research Board
  - Iowa City increased to $100,000, Research Board increase to $120,000

- Construction setback
  - Initially concrete supplier had issues developing the mix
  - Issues getting the electrical permit approved for the project
  - Still working through the permitting issue

Electrical Regulatory Requirements

- Issues meeting electrical regulatory requirements in Iowa
  - How to issue an electrical installation permit?
  - How do inspectors/AHJ ensure compliance?
  - How to ensure electrical safety hazards are addressed?
  - Electrical Equipment/System Certifications?
- Iowa DOT hired a consultant for system evaluation
  - Phase I – identify the issues relative to electrical installation and system evaluation or certification.
  - Amending the NEC to accommodate conductive concrete technology for ice melting
  - Working with UL on revising or development new standards.

Electrical Code Compliance

1. Iowa DOT is working with the National Fire Protection Association (NFPA) on developing and proposing:
   A. A Tentative Interim Amendment to the 2023 NEC
   B. Revised text for the 2026 NEC cycle

2. Changes are to NEC Article 426 Fixed Outdoor Electric Deicing and Snow-Melting Equipment

Underwriter’s Laboratories

- Two Separate Evaluations are being done through Underwriter’s Laboratories
  - Field Evaluation for the site specific installation at the proposed bus stop location in Muscatine Ave in Iowa City, Iowa.
  - Establishing requirements for system evaluation to newly developed standards for future installations to have UL listing

The Path Forward –
Things to think about 1/5

- We are just making a start – A lot to learn yet
- Every new project will help build-up useful information
- More useful in ice prone regions? Probably
- Reduce snow/ice pavement bond – Quicker removal
- Less use of snow/ice removal chemicals
- Asphalt overlay application may be useful

The Path Forward
Things to think about 2/5

"Normal" roads and bridges

- Probably not necessary
- Probably not cost effective
- Electrical power not always available

Apply the technology at appropriate problem areas

- Increase safety Consider B/C?
- Increase mobility Consider B/C

The Path Forward
Things to think about 3/5

Bridges

- Expensive/complicated/hard-to-repair
- Approaches with problematic winter
- Vertical/horizontal geometry issues

Tunnels

- Transition from roadway to tunnel

The Path Forward
Things to think about 4/5

Interstate Rest Areas

- 17 M visitors to the 37 Iowa Rest Areas
- Pedestrian slip and fall winter issues
- Sidewalk/paths from parking lots to buildings
- Sidewalk/paths around buildings

The Path Forward
Things to think about 5/5

City applications

- High pedestrian use sidewalks with winter slip and fall issues
- Refer to Ron’s presentation about the Iowa City bus stop
- High traffic volume approaches/bridges with a history of winter operations problems
- Pedestrian bridges

Question and Answer Session

AASHTO
Innovation Initiative

Thank you!

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