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Improving Bridge Assessment through integration on Visual Inspection and Non-destruction Evaluation Data

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CENTER FOR IMPACTFUL RESILIENT INFRASTRUCTURE SCIENCE & ENGINEERING

Background

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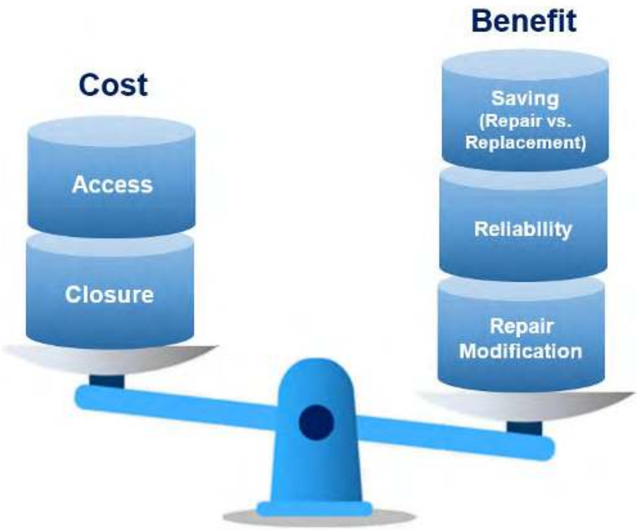
The US Federal Reserve Board:

- Reduction of the national GDP due to failure of civil infrastructure — **1%**
- The America's aging infrastructure — **D+**

www.washingtonpost.com



Cost-effective, continuous, and user-centered assessment and safety evaluation of civil infrastructure are on demand

Research Problem

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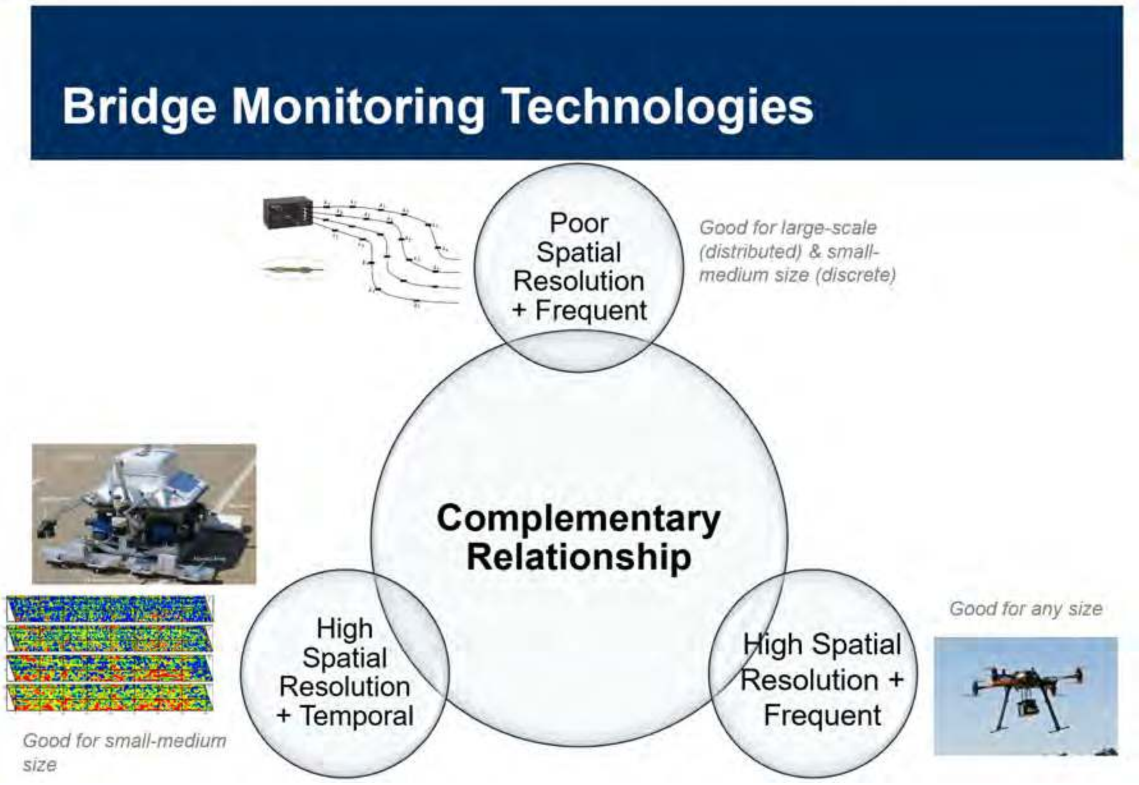
- Large **costs** and relatively **long intervals** between inspections for large structures
- Current assessment approaches are generally **subjective** in nature and provide **only qualitative data** reflective of surface or near-surface condition
- Huge gap exists in:
  - Effective approaches to **fuse** the collected massive NDE **data**
  - Reliability/consistency/implementation of the **UAVs** over the **service life of bridges**



Project Objectives

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- Establish a framework capable of leveraging the data provided by emerging UAV-based and NDE techniques
- Addressing the principal challenges associated with studying the service life of bridge structures:
  - Long-time scales (which requires accelerated aging)
  - The diverse outputs related to bridge condition (in terms of data collected through UAV, NDE, and visual inspection)
- Identifying the synergies among bridge degradation, remaining service life, and the results taken from the multimodal sensing technologies (NDE, and UAV-based)

Project Tasks/Deliverables

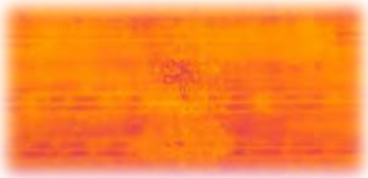
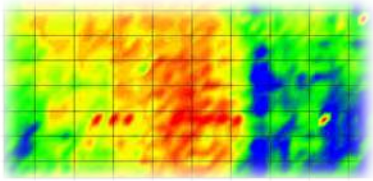
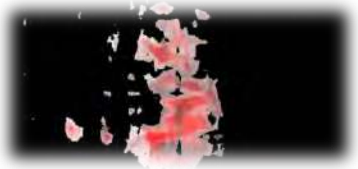
Tasks:

- **Development of Automated Vision-Based Inspection**
  - Collection of high-resolution and high-temporal data from the BEAST facility
  - Advanced data interpretation for UAV data
  - UAV data collection strategy
- **Improvement of Multi-resource NDE Data Interpretation**
  - Individual NDE data interpretation
  - Multi-resource NDE data fusion

Deliverables:

- Final Report
- Technical Articles
- Technical Events (TRB, NEBPP)



The BEAST

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Bridge Evaluation and Accelerated Structural Testing Lab (BEAST):

- Full-scale Bridge Systems
- Accelerated Deterioration
- Speed up 30 times

- **NDE Data Collected from the BEAST:**
  - Electrical Resistance (ER)
  - Ultrasonic Surface Wave (USW)
  - Ground Penetrating Radar (GPR)
  - Half Cell Potential (HCP)

- **UAV Data Collected from the BEAST:**
  - HD Images (UAV/Hand-held)
  - Infrared Images (UAV/Hand-held)

Automated Vision-Based Inspection

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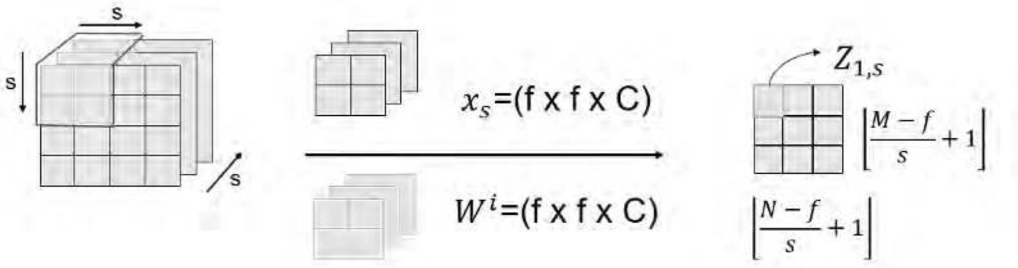
Deep learning can detect and quantify bridge deck surface and subsurface defects!

Feature Extraction

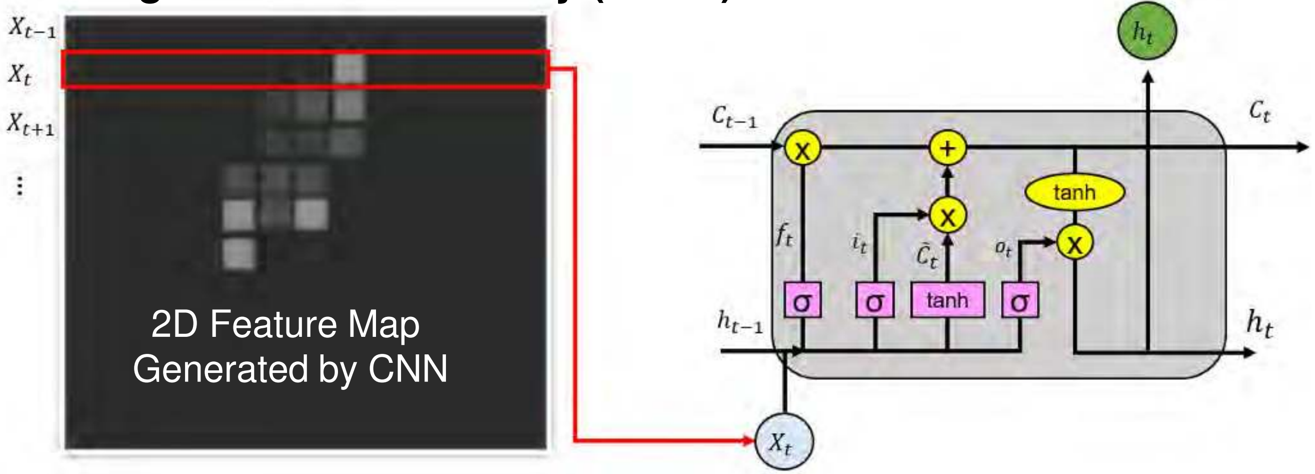
Convolutional Neural Network (CNN)



$$Z_{i,s} = f\left(sum(W^i x_s) + b^i\right)$$

Higher-Level Feature Fusion

Long Short-Term Memory (LSTM)



$$f_t = \sigma(W_f[h_{t-1}, X_t] + b_f)$$

$$i_t = \sigma(W_i[h_{t-1}, X_t] + b_i)$$

$$\tilde{C}_t = \tanh(W_c[h_{t-1}, X_t] + b_C)$$

$$C_t = f_t * C_{t-1} + i_t * \tilde{C}_t$$

$$o_t = \sigma(W_o[h_{t-1}, X_t] + b_o)$$

$$h_t = o_t * \tanh(C_t)$$

Zhang, Barri, Babanajad et al, Engineering, 2020

Automated Vision-Based Inspection

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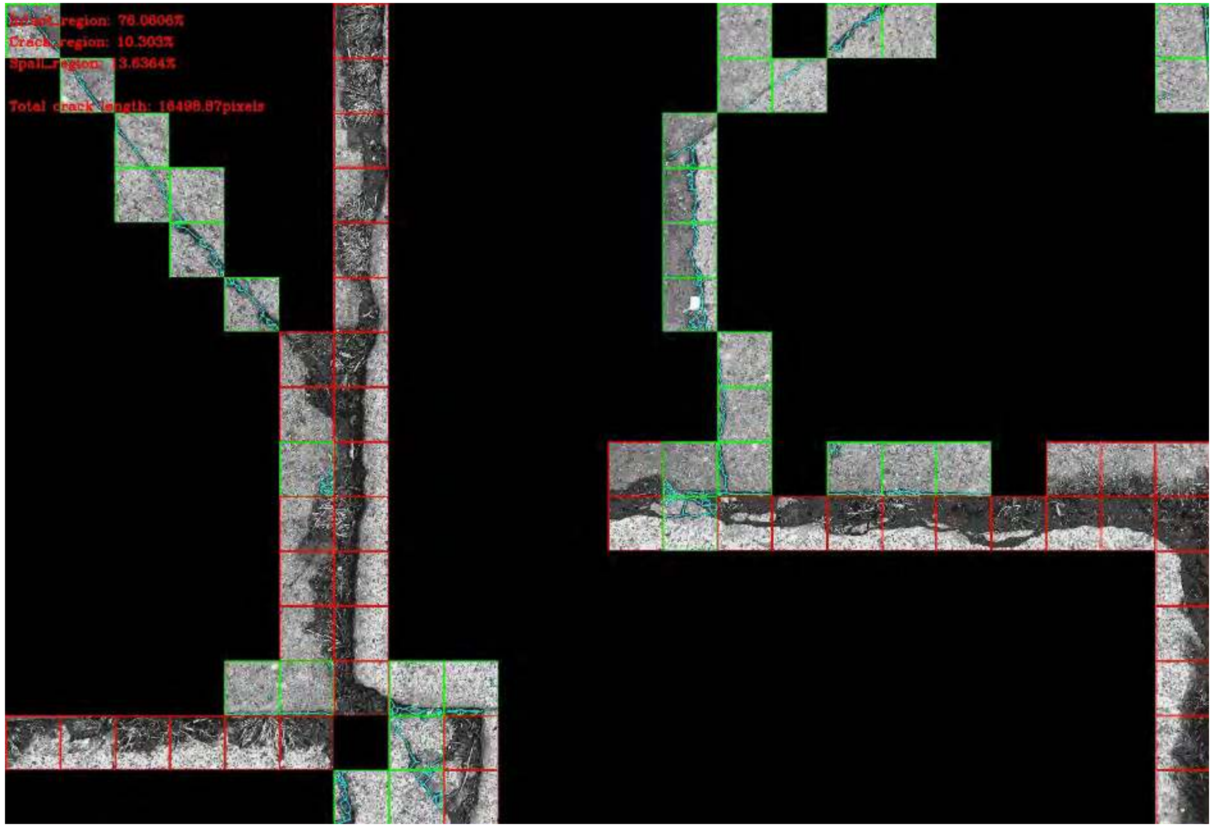
Input

Zhang, Alavi, SPIE, 2021

Output



Crack — Crack Region ☐ Spalling Region ☐

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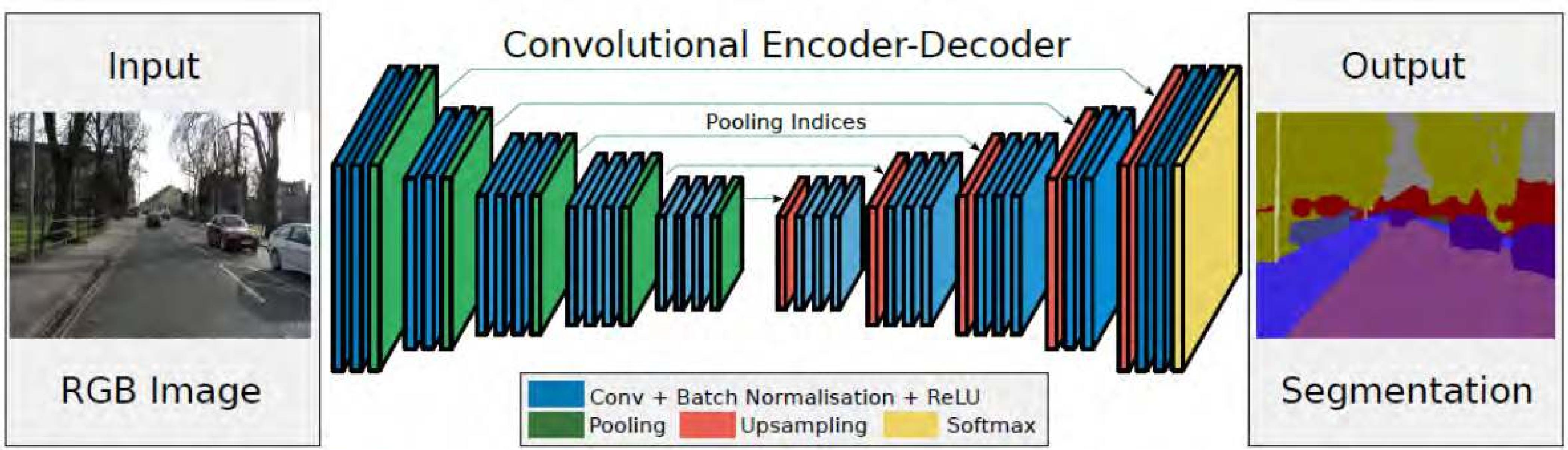
Subsurface Damage Detection (Encoder-Decoder Segmentation Network)



DeepLabV3+Xception backbone

- **DeepLab: Atrous Spatial Pyramid Pooling (ASPP)**
- **Xception: With Depthwise Separable Convolution**

Automated Vision-Based Inspection

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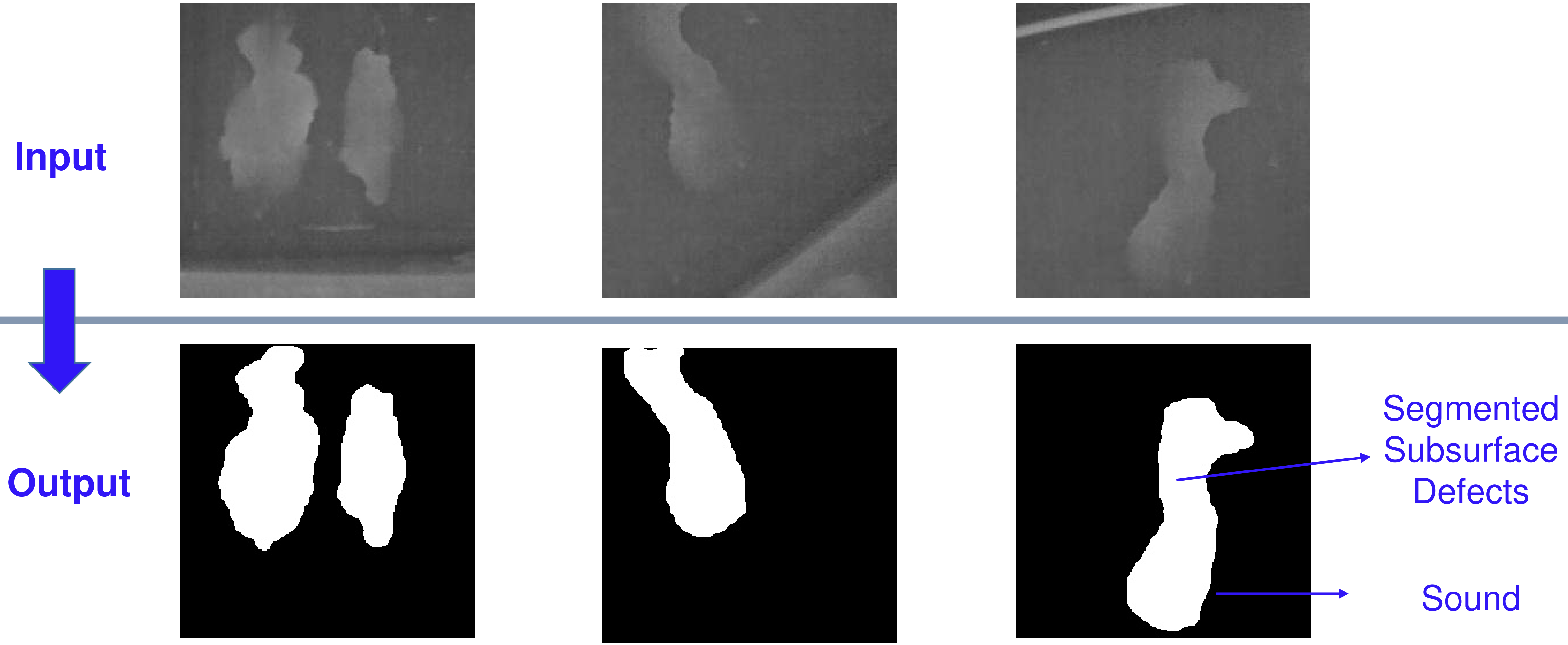

Zhang, Barri, Wan, IBC, 2021

Automated Vision-Based Inspection

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Tool Development for Vision-based Evaluation

An **easy-to-use tool** is developed based on the presented methodologies for **surface** and **subsurface damage evaluation**

Defect detection speed is less than 3 sec/ft^2 of the deck

Zhang, Alavi, Babanajad et al., PennDOT Report No. FHWA-PA-2021-012-IRISE WO 01, 2021

Automated Vision-Based Inspection

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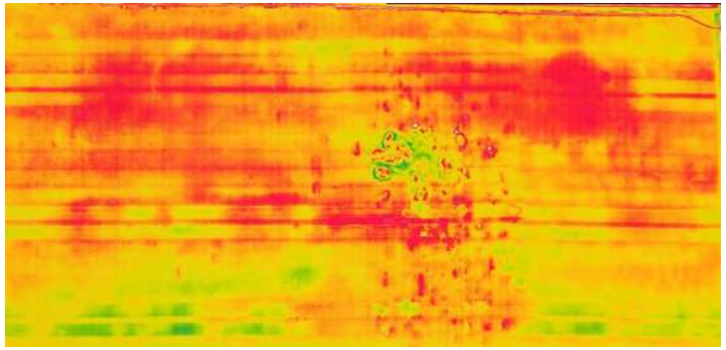
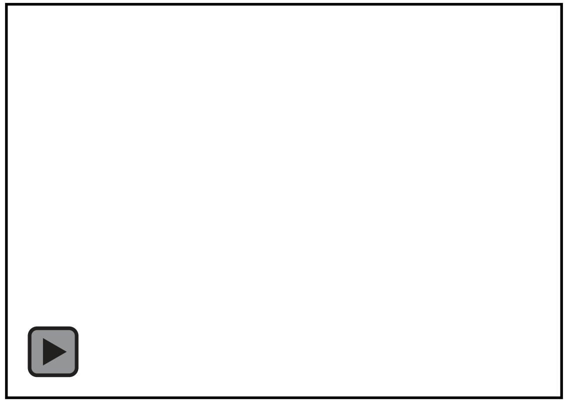
Implementation and Validation on BEAST

Input

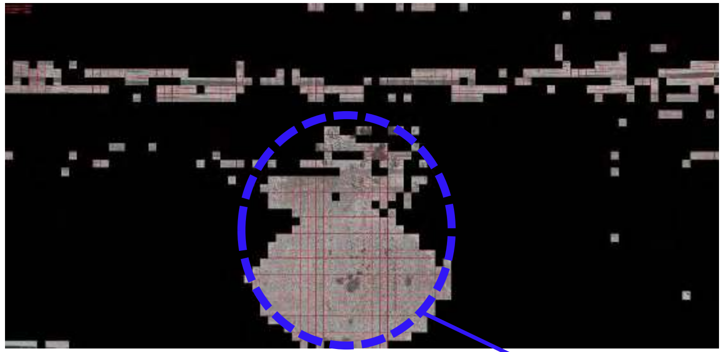
25 ft

50 ft

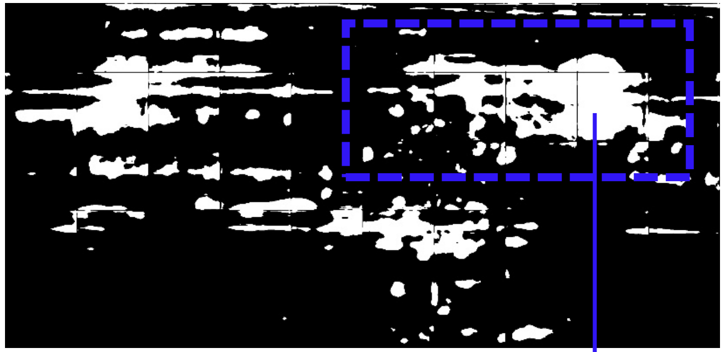




Output



Surface Defects



Potential Subsurface Defects

Zhang, Ro, Gong et al., IWSHM, 2021

Automated Vision-Based Inspection

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UAV Data Collection Strategy

Challenges:
- IR image quality can be **affected** by **many factors**
- Investigation in UAV IR data **collection strategy** is necessary

	Collection #1	Collection #2	Collection #3
Time	Morning (10 am - noon)	Afternoon (3-5 pm)	Evening
Distance from Deck (feet)*	30/40/50/60/70/80	30/40/50/60/70/80	30/40/50/60/70/80
Camera angles	Vertical/Oblique	Vertical/Oblique	Vertical/Oblique
Overlap	75%	75%	75%
Deck condition	Dry	Dry	Dry
HD Images	Same setting as IR image (only before sunset)		

Automated Vision-Based Inspection

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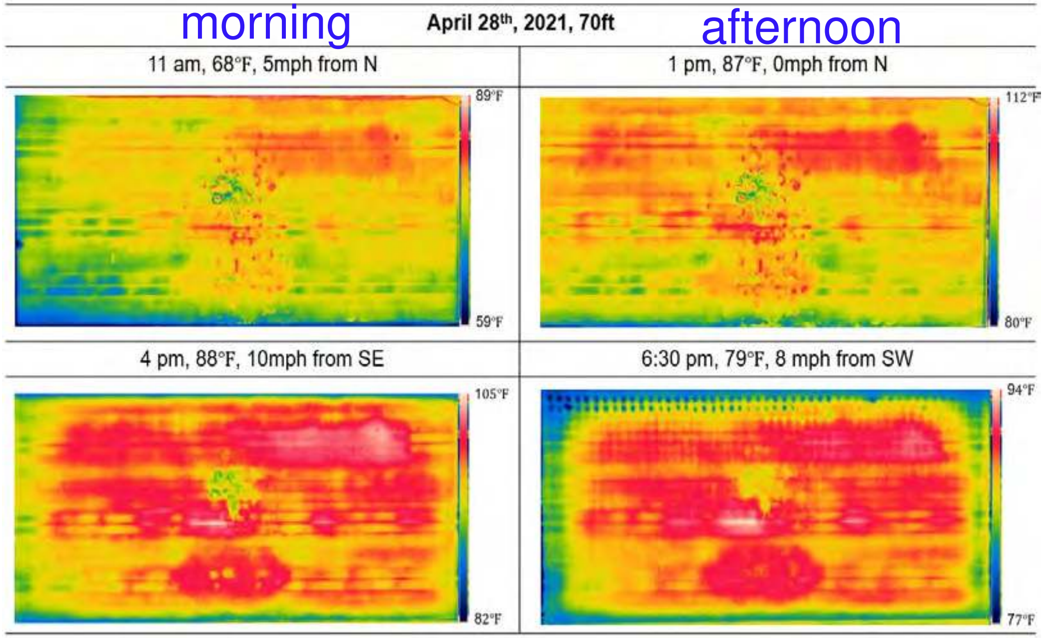
- The necessary temperature change for IRT under passive conditions is **at least 8.2°C**.
- The temperature changes were **11.1°C** at the closest climatological substation to the BEAST facility on **April 28th, 2021**

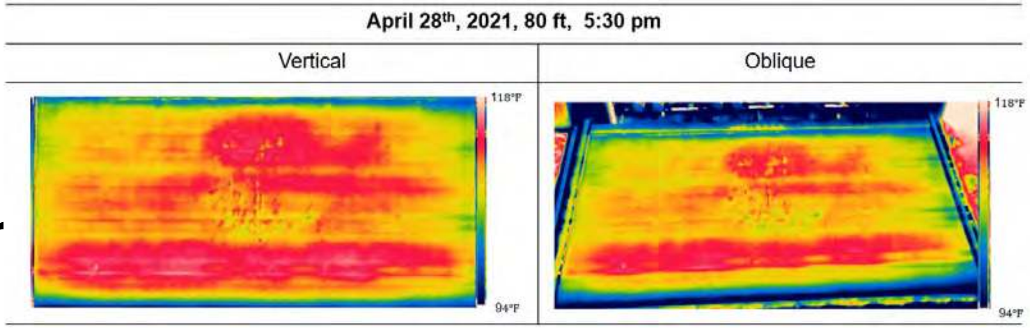
Time Factor

morning afternoon



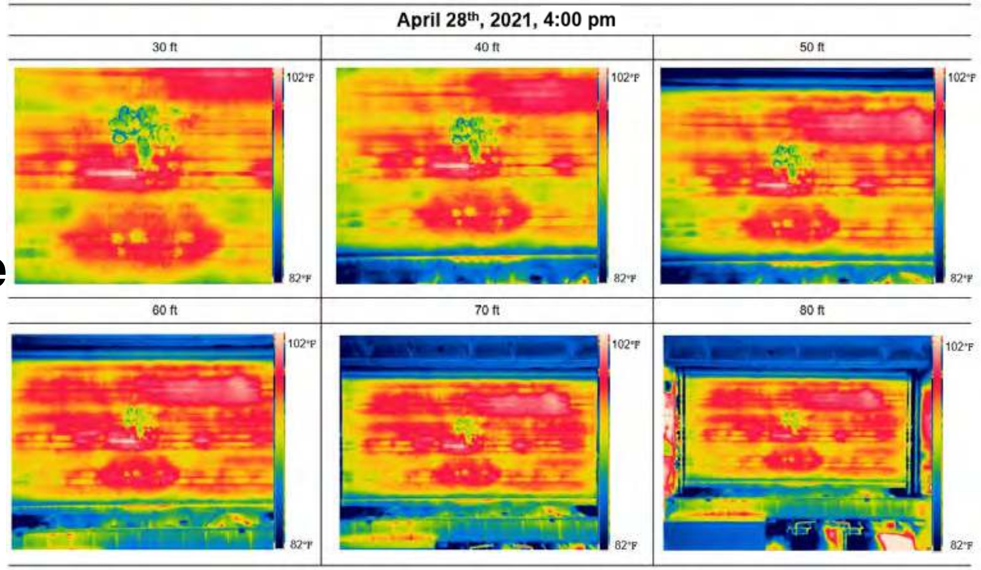
Significant effect

Angle Factor



Moderate effect

Distance Factor



No significant effect

Zhang, Ro, Gong et al., IWSHM, 2021

Multi-resource NDE Data Interpretation

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Multi-resource Data Collected from the BEAST

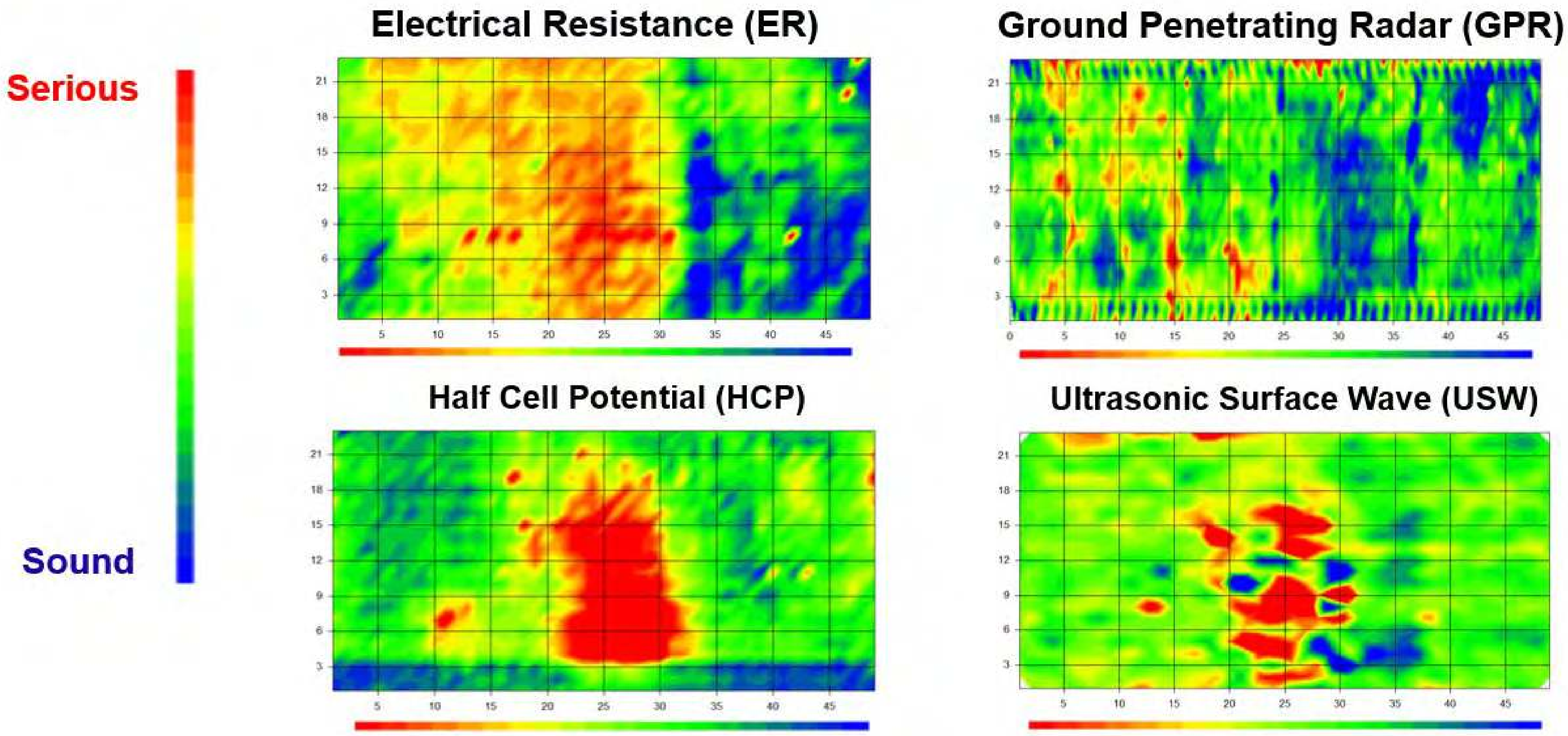
10 rounds of NDE data collection have been conducted

Data Collection Date	Cumulative Live Load Cycles	Cumulative Freeze-thaw Cycles	Deck Condition Rating (Visual Inspection)	NDE Data Collection (IE/ USW/ER/GPR/HCP)
11/2019	185000	8	-	X
01/2020	385000	24	-	X
02/2020	572000	35	X	X
06/2020	717000	39	-	X
11/2020	914000	48	X	X
12/2020	1114000	56	-	X
03/2021	1323270	70	X	X
04/2021	1374876	73	X	X
06/2021	1671506	85	X	X
07/2021	1866006	85	X	X

Multi-resource NDE Data Interpretation

Statistical Analysis for Individual NDE Data

Condition maps (April 2021)



Multi-resource NDE Data Interpretation

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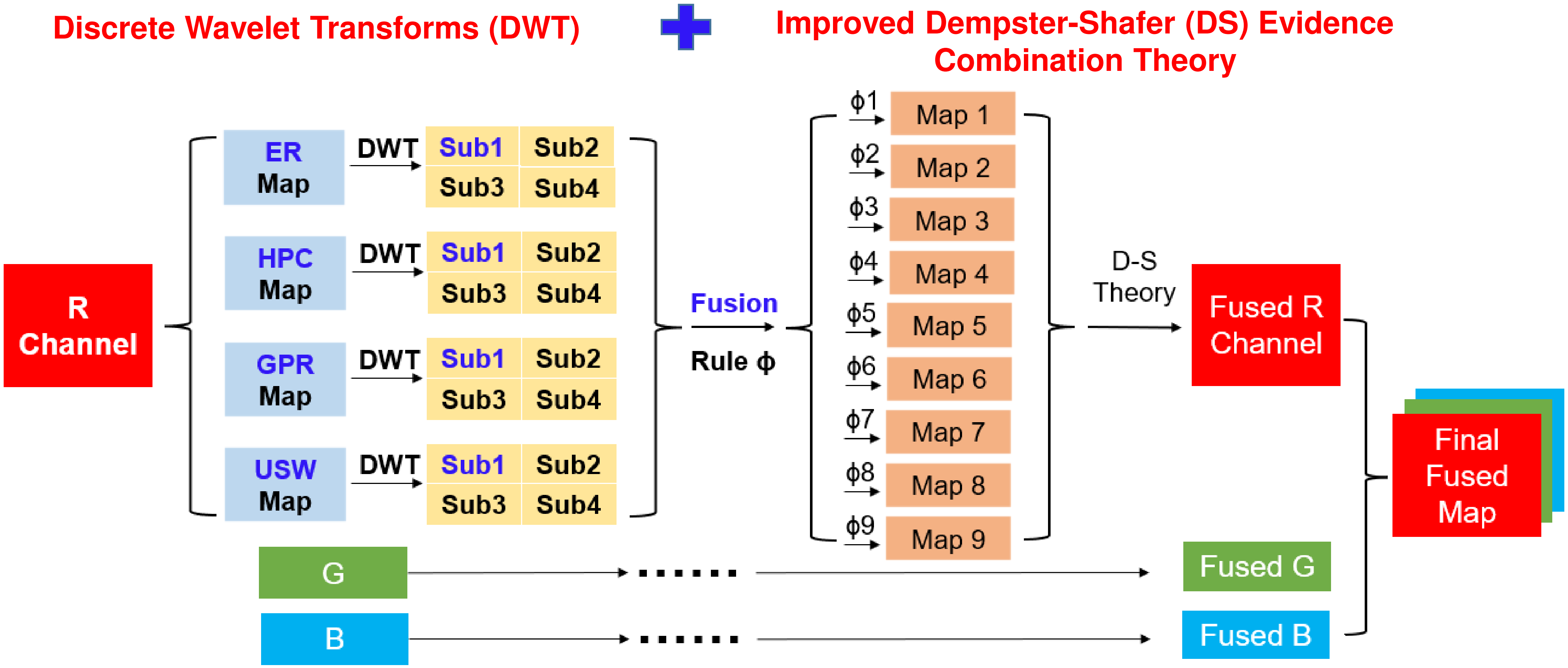
Multi-resource NDE Data Fusion



Zhang, Babanajad, Ro et al., Automation in Construction, 2022

Multi-resource NDE Data Interpretation

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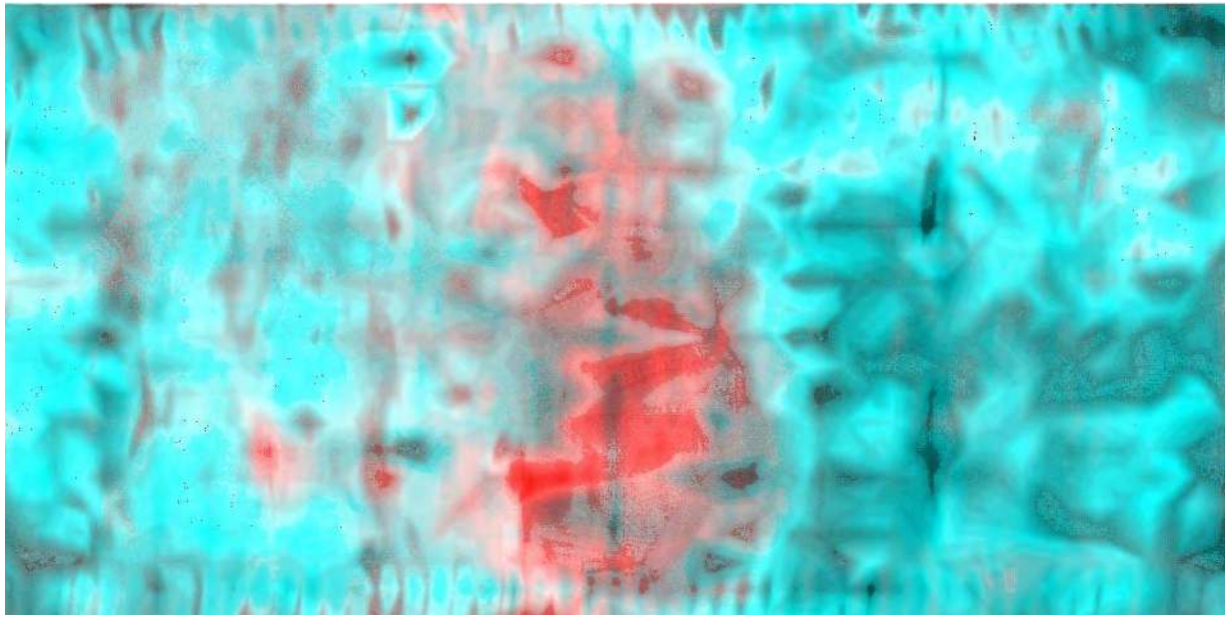
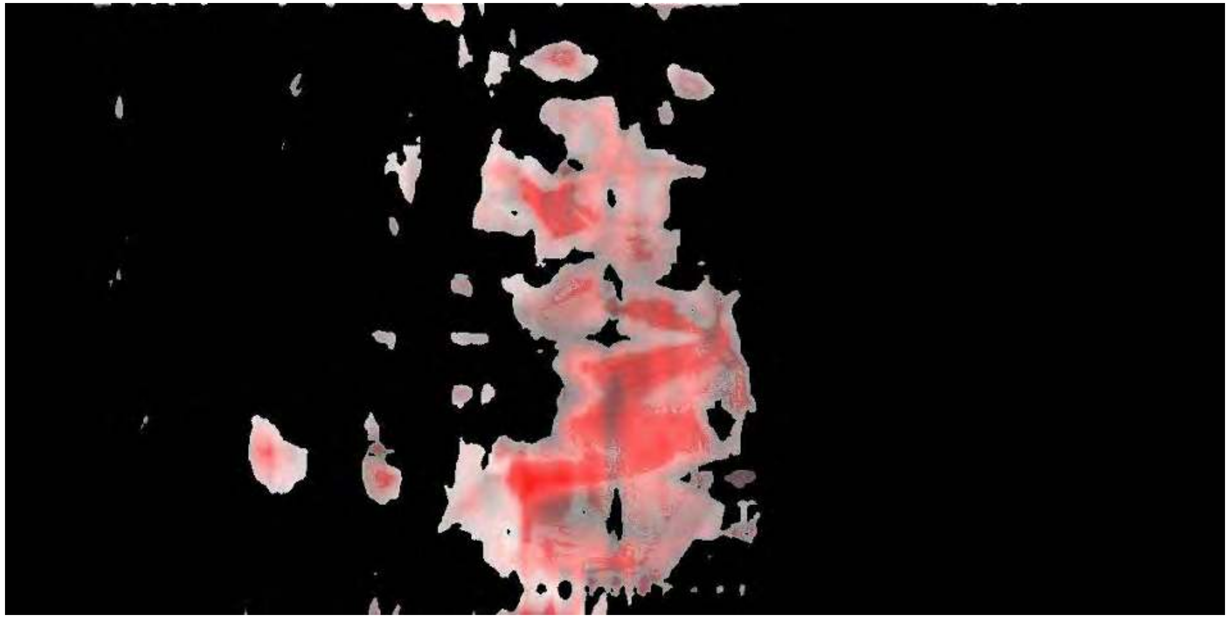
Multi-resource NDE Data Fusion

Since **red** color means high probability of existing **damages**, red parts are segmented out





Zhang, Babanajad, Ro et al., Automation in Construction, 2022

Multi-resource NDE Data Interpretation

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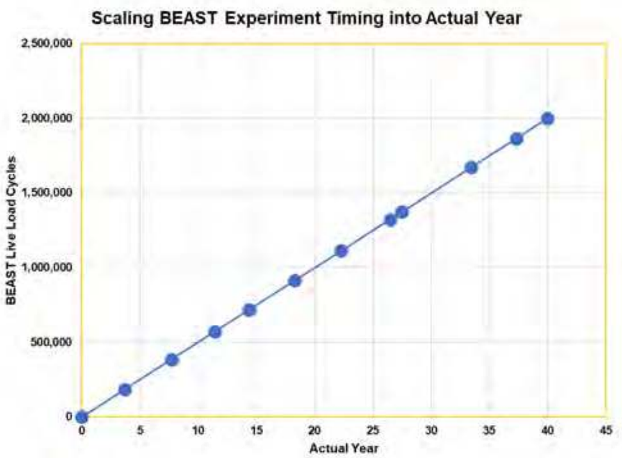
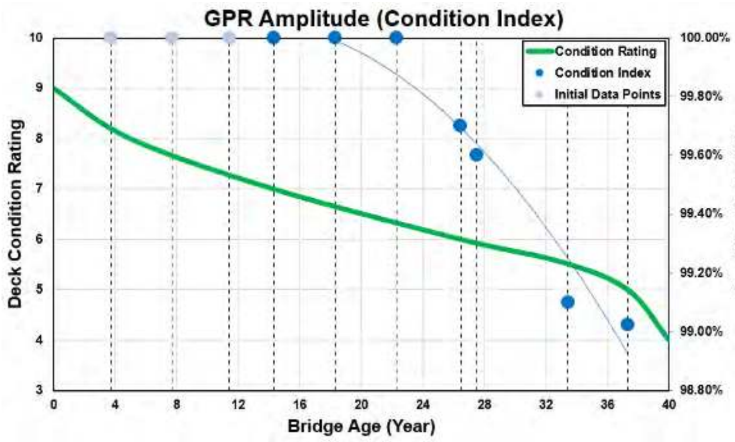
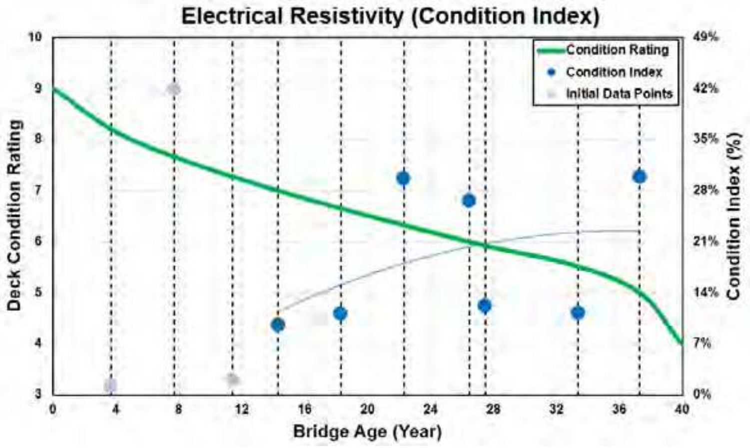
Comparison Between Individual NDE Results and Fused Results

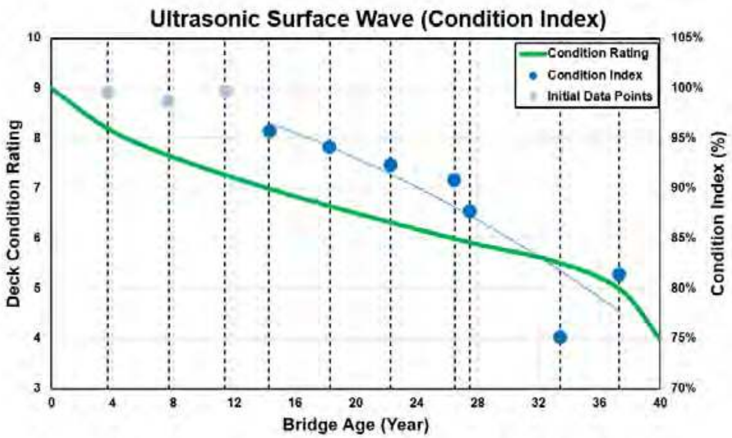


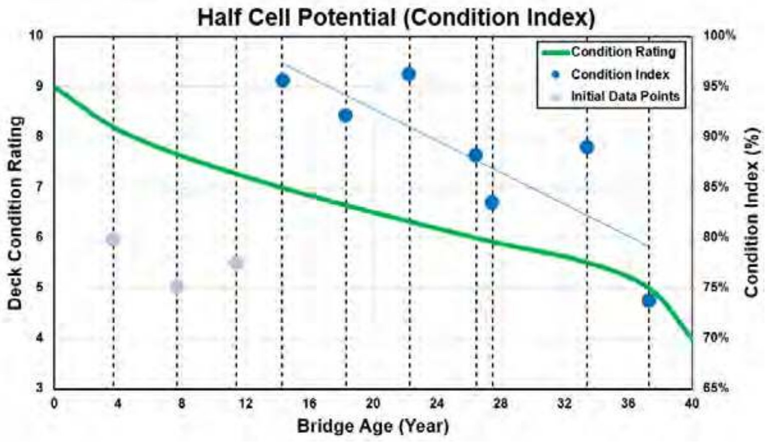
Conversion of BEAST live-load cycles into actual years





Individual NDE result does NOT match the trend well





Zhang, Babanajad, Ro et al., Automation in Construction, 2022

Multi-resource NDE Data Interpretation

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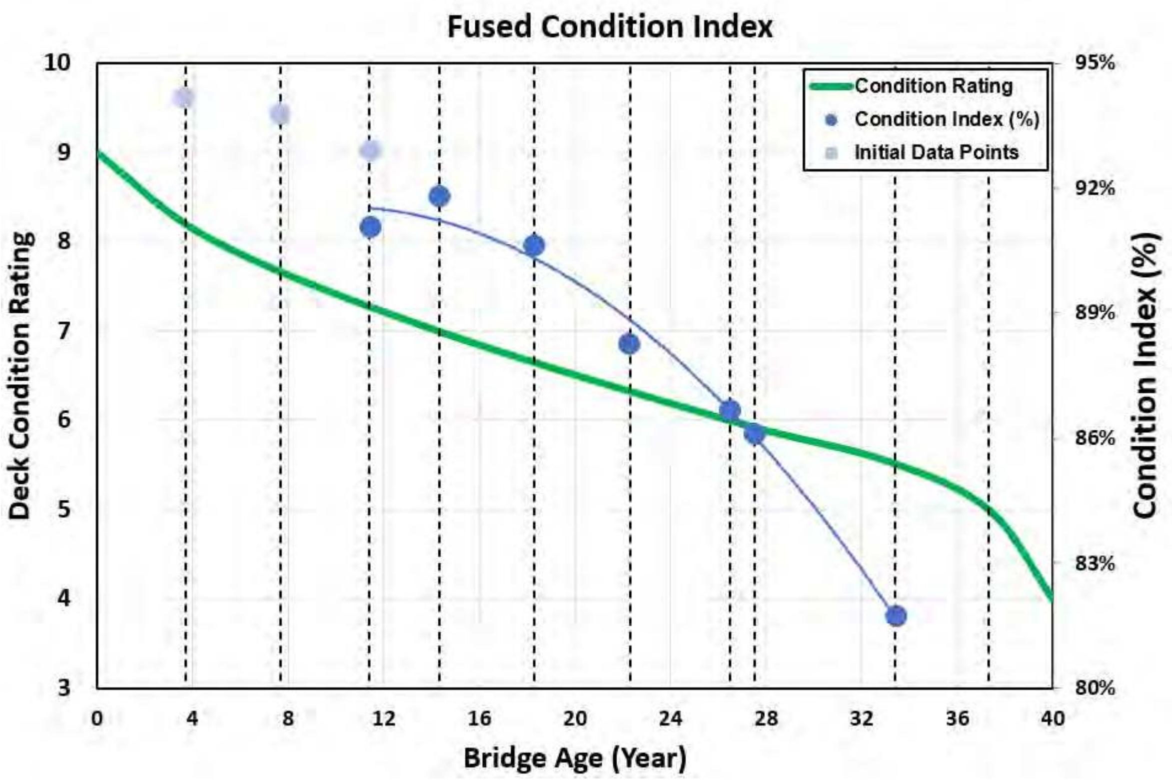
Comparison Between Individual NDE Results and Fused Results

Individual NDE result does match the trend well



Zhang, Babanajad, Ro et al., Automation in Construction, 2022

Summary

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- **Automated Vision-based Evaluation**
  - Surface and subsurface defects detection methodologies
  - An easy-to-use tool for DOTs and large–scale implementation
  - UAV data collection strategy
- **Multi-resource NDE Data Interpretation**
  - Individual analysis of NDE data collected from BEAST
  - Multi-resource NDE data fusion method
  - Comparison of individual NDE results and fused results

Reference

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The project is sponsored by Pennsylvania Department of Transportation.

Project Panel

Tom Macioce, PennDOT
Keith Cornelius, PennDOT
Rich Runyen, PennDOT
Brian Rampulla, PennDOT
Shelley Scott, PennDOT

Jonathan Buck, FHWA
Mike Burdelsky, Allegheny County
Mike Pichura, MBI

Awards by Gloria Zhang:

Best Paper Award, James D. Cooper Student Paper Competition, International Bridge Conference (IBC)

Best Poster Award, Advancing Research through Computing (ARC) Competition

Best Paper Award, Association for Bridge Construction and Design (ABCD)

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pennsylvania
DEPARTMENT OF TRANSPORTATION

RUTGERS
Center for Advanced Infrastructure and Transportation

WJE
ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS
Wiss, Janney, Elstner Associates, Inc.

Reference

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1. Zhang Q., Babanajad S.B., Ro S. H., Braley J., Alavi A.H., “Bridge deck assessment via multi-resource nondestructive evaluation data fusion,” Automation in Construction, In review, 2022.
2. Zhang Q., Barri K., Babanajad S. K., Alavi A. H. , “Real-time detection of cracks on concrete bridge decks using deep learning in frequency domain,” Engineering, 2020.
3. Zhang Q., Babanajad S. K., Moon F., Alavi A. H., ”Automated detection and quantification of cracks and spalls in concrete bridge decks using deep learning”, 100th TRB Annual Meeting, 2021
4. Zhang Q., Alavi A. H., “Automated two-stage approach for detection and quantification of surface defects in concrete bridge decks”, Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XV, 2021
5. Zhang Q., Barri K., Wan Z, “A deep learning-based autonomous system for detection and quantification of delamination on concrete bridge decks”, International Bridge Conference, In press, 2021.
6. Zhang Q., Ro S.H., Gong J., Moon F., Alavi A.H., “Recent advances in bridge condition assessment using unmanned aerial vehicles”, 13th International Workshop on Structural Health Monitoring, Stanford, California, 2021.
7. Zhang Q., Alavi A., Babanajad S., Moon F., Braley J., Gucunski N., “Improving Bridge Assessment through the Integration of Conventional Visual Inspection, Non-Destructive Evaluation, and Structural Health Monitoring Data,” Pennsylvania State Department of Transportation, Report NO. FHWA-PA-2021-012-IRISE WO 01, 2021.

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Questions?

PennDOT (p 118)

Condition Rating for Concrete Bridge Deck Evaluation:

		Condition Indicators					
Category Classification	Rating	Deck Area		Electrical Potential	Deck Area	Chloride Content (#/CY)	Deck Area
		Visible Spalls	Delam-ination				
Category #3 Light Deterioration	9	none	none	0.0	none	0	none
	8	none	none	0.0 < E.P.< 0.35	none	0 < C.C.<1	none
	7	none	< 2%	0.35 < E.P.< 0.45	≤ %5	0 < C.C.<2	none
Category #2 Moderate Deterioration	6	< 2% spalls or sum of all deteriorated and/or contaminated deck concrete (≥2#/C.Y.Cl) < 20%					
	5	< 5% spalls or sum of all deteriorated and/or contaminated deck concrete 20% to 40%					
Category #1 Extensive Deterioration	4	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete 40% to 60%					
	3	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete > 60%					
Structurally Inadequate Deck	2	Deck structural capacity grossly inadequate					
	1	Deck has failed completely – Repairable by replacement only					
	0	Holes in deck – Danger of other sections of deck failing					

Notes: Rating 9 - No deck cracking exists. Rating 8 - Some minor deck cracking is evident

- To achieve better visualization, a 3D model of the BEAST has been developed as follows:

- Application:
  - Virtual bridge inspection
  - Bridge inspection training
  - Better post data interpretation and visualization