INSPIRE

INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

Annual Report: Year 1

Pooled-fund Project No. TPF-5(395)

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Outline

- Project Overview
- Bridge Inspection Robot Deployment Systems (BIRDS)
- Bridge Selection for Inspections
- Process to Finalize the Bridge Selection
- Concluding Remarks

Project Overview

- The goals of this pooled-fund initiative are
  - To engage closely with several state Departments of Transportation (DOTs) in the early stage of technology development at the INSPIRE University Transportation Center, and
  - To leverage the center resources to develop case studies, protocols, and guidelines that can be adopted by state DOTs for bridge inspection without adversely impacting traffic flow.
- This initiative involves
  - Technology integration, field demonstration and documentation of a robotic system of structural crawlers, UAVs, BIRDS, NDE devices, sensors, and data analytics

Project Overview

- **Objectives**
  - Develop inspection/operation protocols for various types of bridges with the robotic system integrated into current practice.
  - Compare and correlate bridge deck inspections from the top and bottom sides of decks to understand the reliability of traffic disruption-free bridge inspection from the underside of decks.
  - Develop the design guidelines of measurement devices on a robotic platform for the detection of surface and internal damage/deterioration in structural elements, and for the change in lateral support of foundations.
  - Test and demonstrate data fusion and analytics of measurements taken from various imaging and sensing systems for consistency and reliability.
  - Develop the best practices on bridge inspection using the robotic system.

Project Overview

- **Five-year Performance Period**
  - **August 1, 2019, to July 31, 2024**
- **Project Schedule by Year**

Task	Year				
	1	2	3	4	5
1. Bridge selection for manual and automated inspections	K				
2. Operation of multimodal unmanned systems					
3. Correlation of top and bottom deck inspections					
4. NDE and sensing integration into visual inspection					
5. Case studies with a representative bridge inventory					
6. Protocol and guideline modification			M		
7. Limited release of protocols, guidelines, and criteria					
8. Final reporting and curation of main findings					D F

Notes:
- K Kickoff meeting at the beginning of this contract
- M Mid-term report due at the end of 3 years
- D Draft report/deliverables due 60 days prior to the contract termination date
- F Final report/deliverables due by the contract termination date

Project Overview

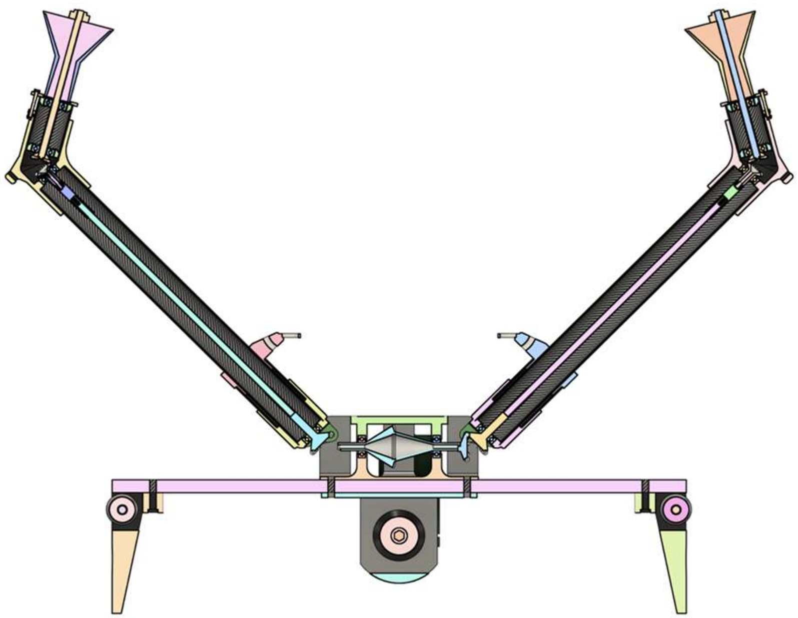
- **Task 1. Bridge Selection for Manual and Automated Inspections**
  - Develop a selection protocol of bridges that are appropriate for both manual visual inspection and automated NDE. Thus, the performance of robot-based NDE can be compared with the current practice of visual inspection. The main parameters considered in this selection include span length, bridge type, accessibility, and importance. For example, river-crossing bridges may be inspected in great depth with advanced technologies, while simple highway bridges with easy access may not require any robotic platform during inspection.

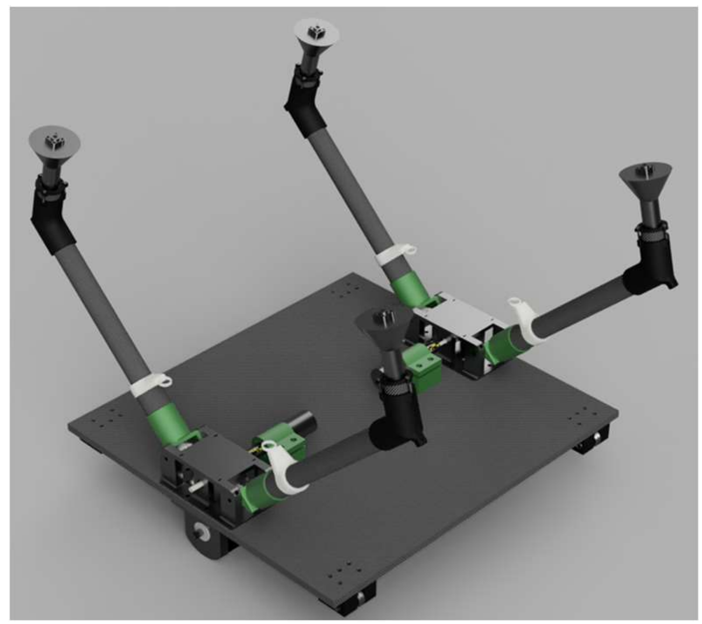
Project Overview

- **Task 2. Operation of Multimodal Unmanned Systems**
  - **Develop a field test facility (e.g., recreational vehicle for a three-person crew) of the robotic system, including the BIRD system equipped with two infrared cameras (e.g., dual-sensor FLIR DuoTM Pro) and one impact sounding/echo device for RC elements, and a structural crawler for other bridge elements. The inspection crew will consist of a research engineer in bridge inspection and maintenance, a research assistant professor in system integration and robotics, and a rotating graduate student intern.**

BIRDS Integration

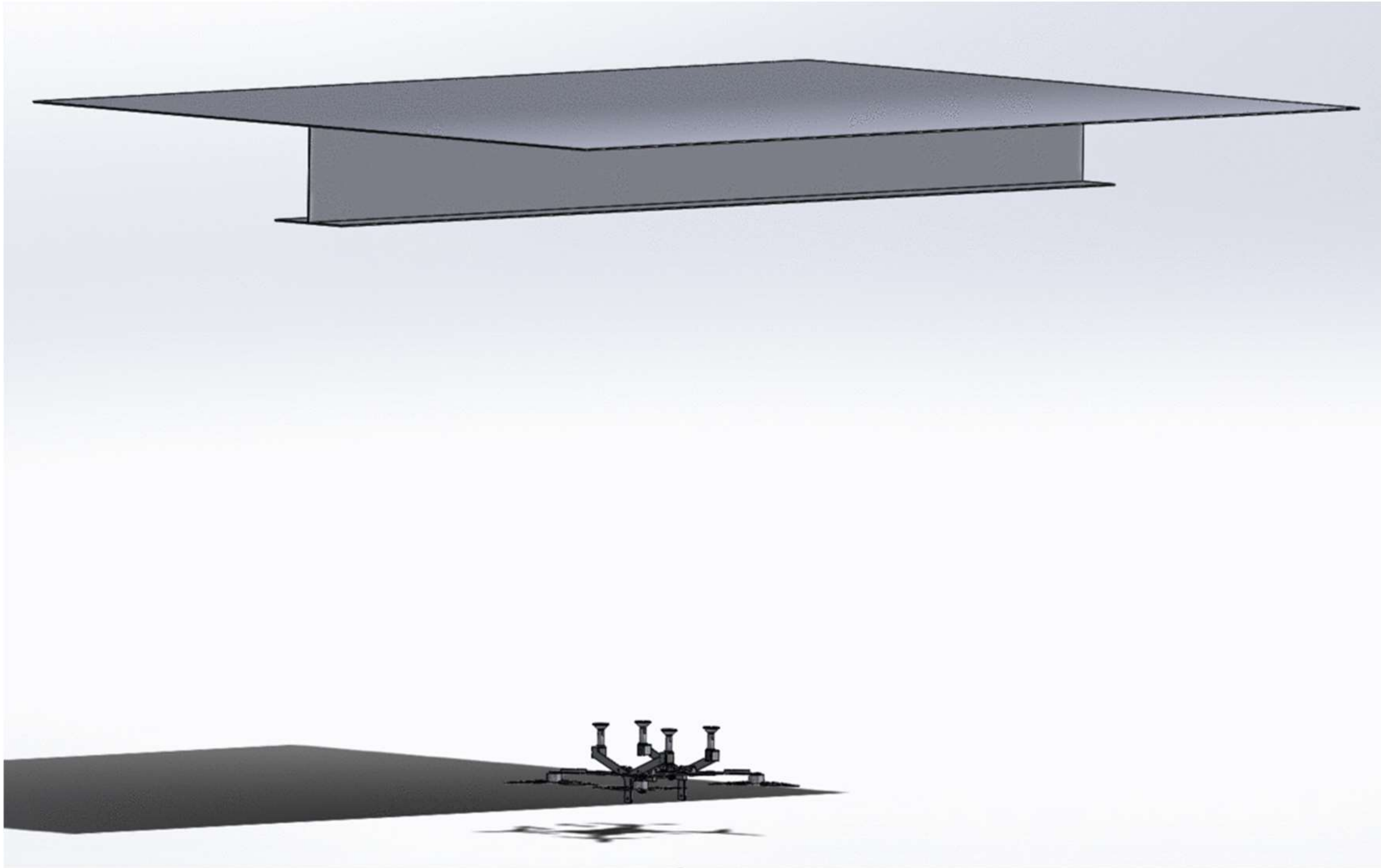
- **Example Technology 1 – Bridge Engaged Multimodal Unmanned Vehicle**





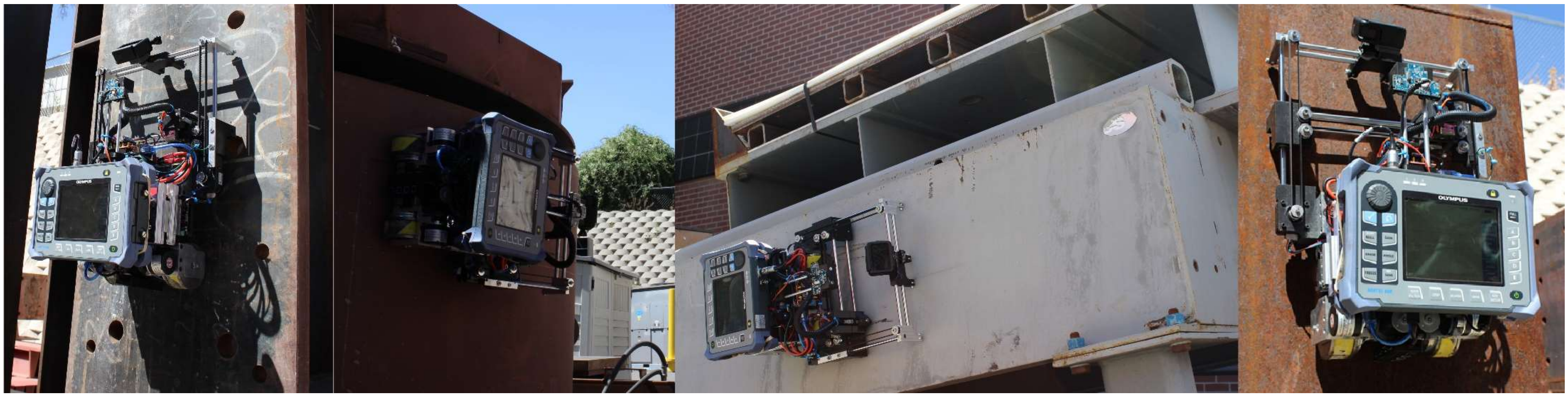
BIRDS Integration

- Flying -> attaching -> traversing -> detaching



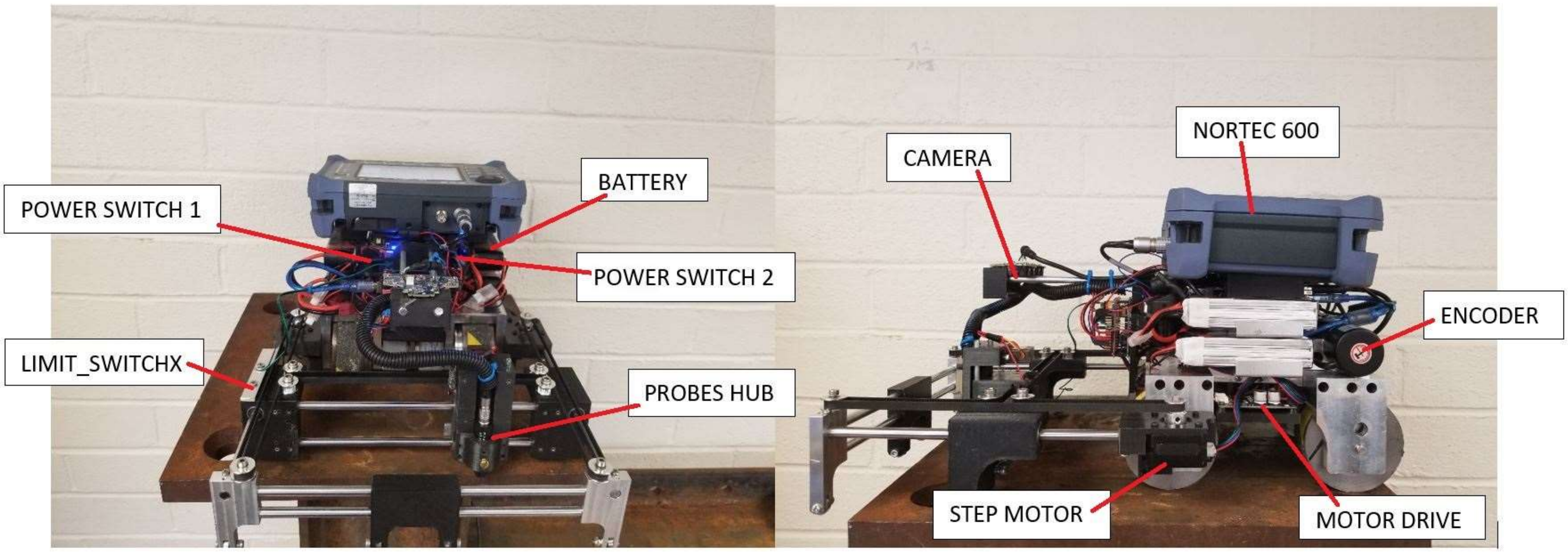
BIRDS Integration

- **Example Technology 2 – Bridge Engaged Climbing Robot**



BIRDS Integration

- **Example Technology 2 – Bridge Engaged Climbing Robot**



BIRDS Integration

- **Example Technology 3 - Smart Rock Positioning for Scour Depth Measurement**
  - ➢ **A smart rock rolls to the bottom of a scour hole when formed with unknown location and depth as deposits around the hole are washed away.**
  - ➢ **A smart rock is one or more gravity-controlled magnet(s) encased in a fiber-reinforced concrete sphere to minimize the influence of steel rebar in bridge piers on magnetic field measurements.**
  - ➢ **Spherical encasement facilitates the rolling of a smart rock to the bottom of a scour hole.**

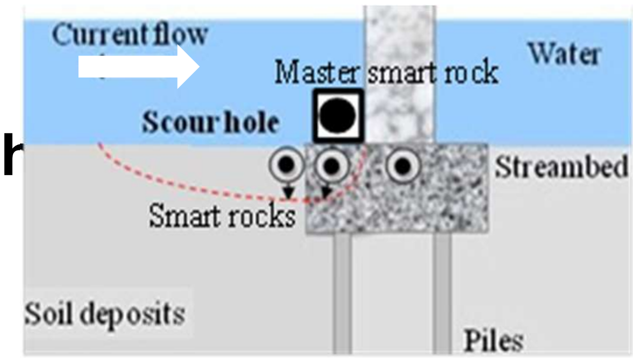
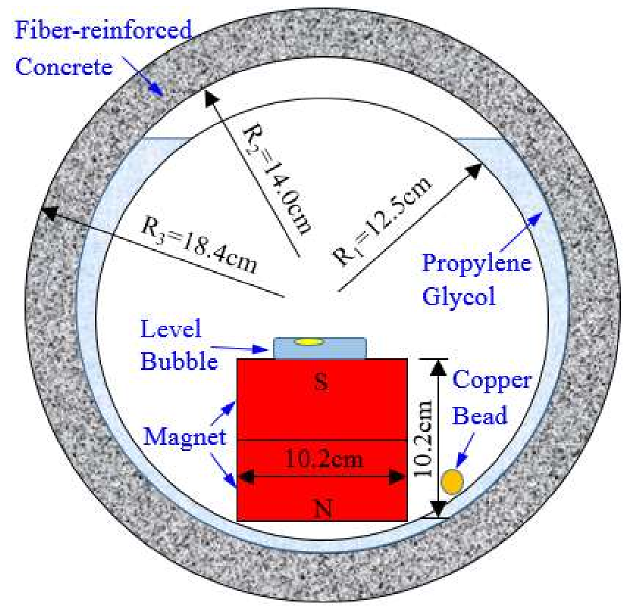


Fig. 1 Maximum Scour Depth Monitoring

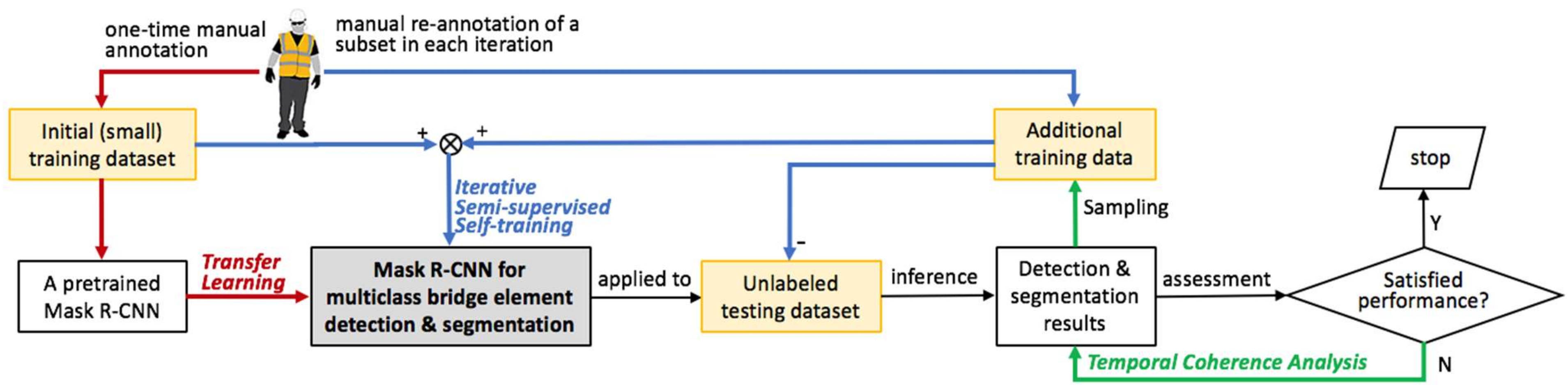


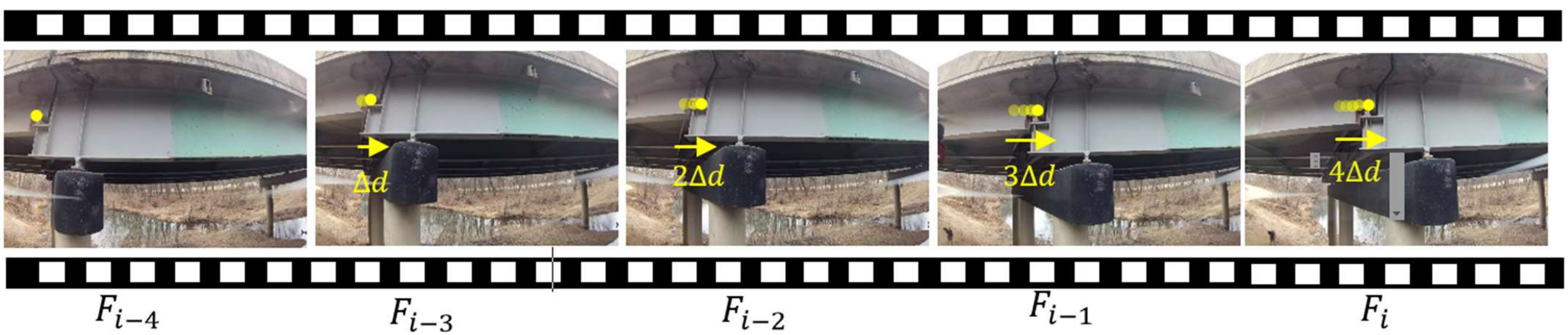
BIRDS Integration

- **Example Technology 3 - Field Validation**
  - ➢ **Smart Rock Deployment and Measurement at Pier 7 of the Roubidoux Creek Bridge (I-44W)**

BIRDS Integration

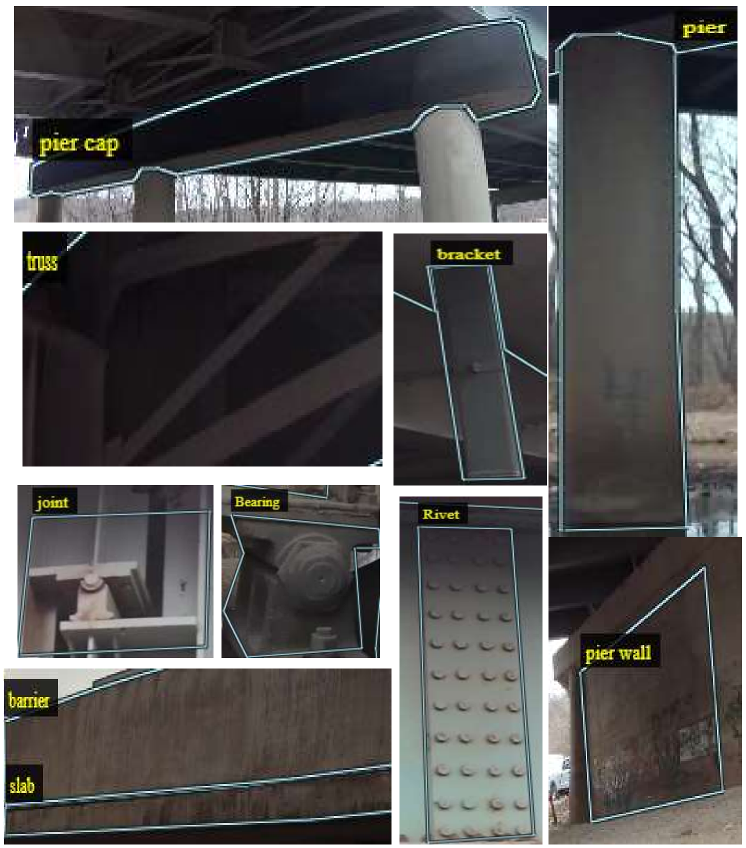
- **Example Technology 4 – Assistive Intelligence for Extraction of Objects**





BIRDS Integration

- **Example Technology 4 – Case Study with 212 Images**
  - **1,872 labeled objects in 10 classes**



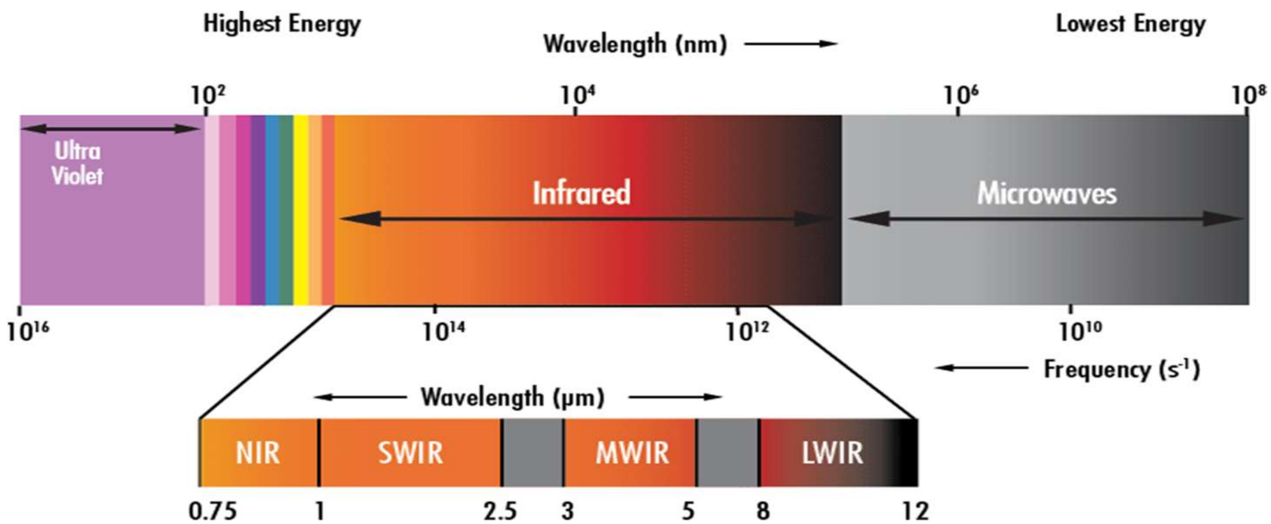
		Transfer learning	Iterative S^3T		
Index of iteration, l		0	1	2	3
IoU = 0.5	Precision (%)	80.3	81.7	90.7	91.8
	Recall (%)	74.4	90.3	90.1	93.6
	f1-Score (%)	77.2	85.8	90.4	92.7

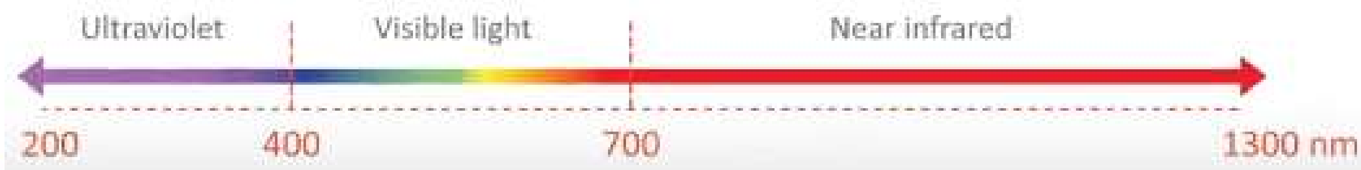
10 classes of objects

1) Barrier
2) Slab
3) Bearing
4) Pier
5) Pier cap
6) Pier wall
7) Rivet
8) Truss
9) Bracket
10) Joint

BIRDS Integration

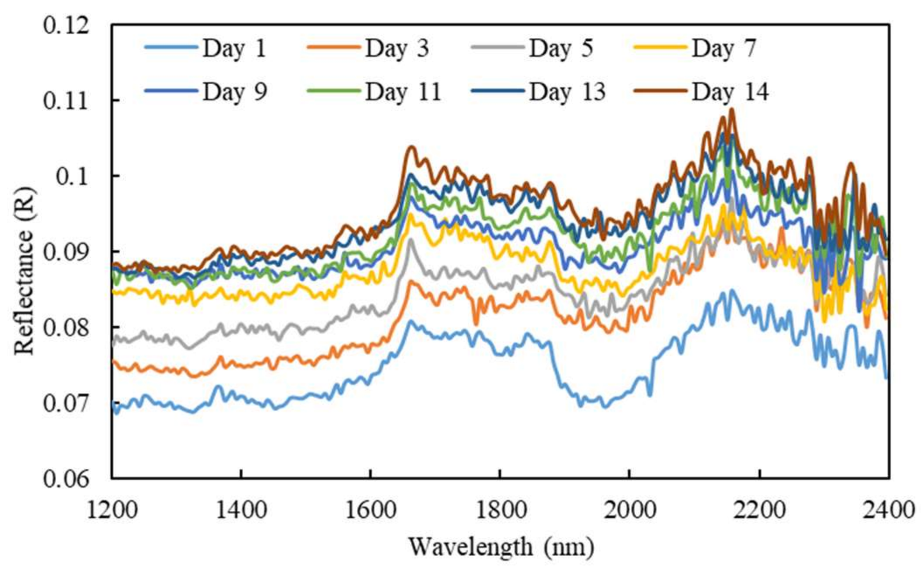
- **Example Technology 5 – Hyperspectral Imaging for QC and Condition Assessment**
  - ➢ **Headwall Co-Aligned Dual-Sensor Hyperspectral Camera (400 – 2500 nm)**
  - ➢ **VNIR (400 – 1000 nm) and SWIR (900 – 2500 nm)**





BIRDS Integration

- **Example Technology 5 – Potential Applications**
  - Quality control of time-sensitive concrete construction in highway pavements and bridges
  - Quality control of steel surface preparation for painting
  - Painting and steel condition assessment
  - Reinforced concrete condition assessment (scaling, roughening, rebar corrosion indication, etc.)



Bridge Selection for Inspections

- Purpose of Bridge Selection
- Participating States
- Bridge Database
- Selection Factors Considered
- State Grouping by Material Type
- Access to Bridge Sites
- Recommended Bridge Details
- Distribution of Bridges by State

Purpose of Bridge Selection

- **A sample of representative bridges to test robotic technologies in various applications is small enough to permit data collection efforts within budget constraints.**
  - ➢ **Up to nine (9) similar highway bridges/year in three (3) age groups or one long-span bridge/year from each participating state will be tested starting in the 2nd year.**
  - ➢ **The Long Term Bridge Performance (LTBP) Program data will be leveraged to develop deterioration curves.**
- **Modify the LTBP Bridge Selection Methodology**
  1. **Determine the most common bridge types that predominate now and are likely to do so in the future, which also meets the objectives of this initiative:**
     - ✓ ***Steel-girder bridges or***
     - ✓ ***Prestressed concrete-girder bridges***

Purpose of Bridge Selection

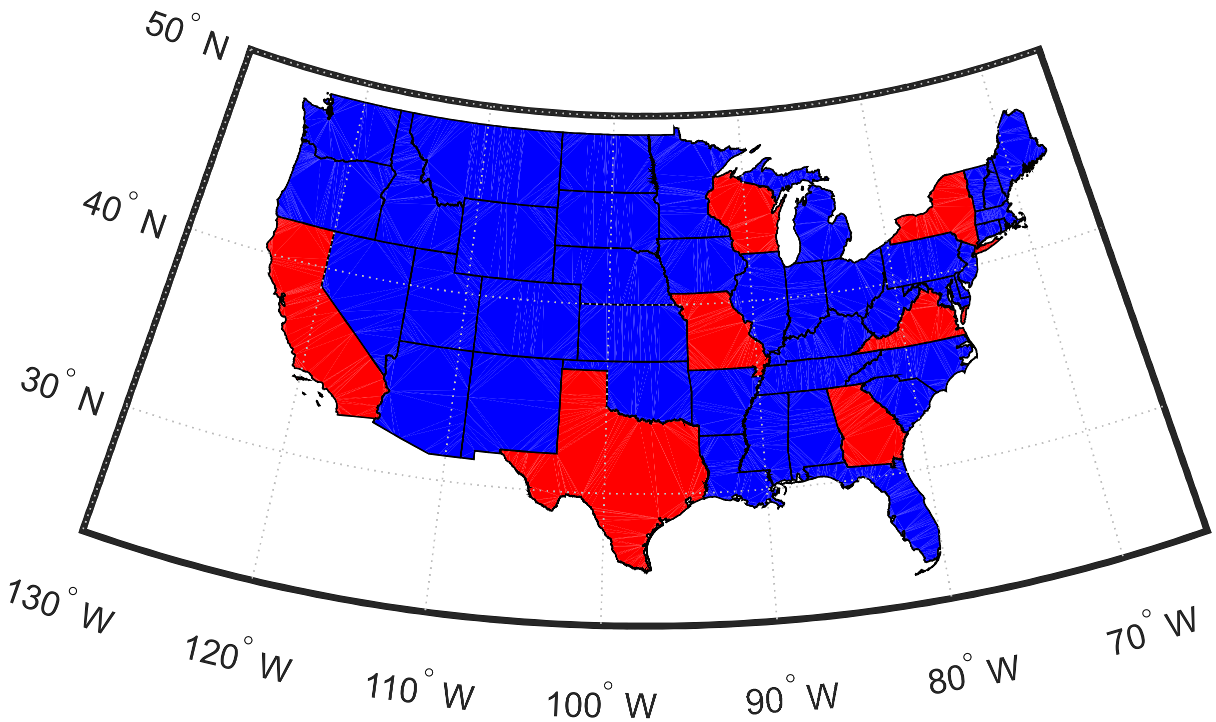
2. **Identify representative clusters of each primary bridge type within various regions of the United States, considering the following factors:**
   - ✓ ***Climate/environmental conditions and regional/State maintenance practices. The climatic zones defined by the Department of Energy (DOE) are used.***
   - ✓ ***Concentrated geographic areas to allow for cost-effective data collection efforts***
3. **Determine the level of detail appropriate for data collection efforts for each bridge within geographic clusters.**
   - ✓ ***An attempt will be made to carry out the most detailed NDE, structural characterization through field instrumentation, material sampling, and visual inspection for each bridge identified.***

Purpose of Bridge Selection

4. **Perform legacy data mining from plans, inspection reports, maintenance records of all the candidate bridges to determine which bridges represent a geographic cluster with the following specific criteria:**
   - ✓ ***State owned***
   - ✓ ***Not over a railroad***
   - ✓ ***Max span length between 10 and 50 m***
   - ✓ ***Maximum of four lanes on bridge***
   - ✓ ***Average daily traffic (ADT) less than 50,000***
   - ✓ ***Built after 1970***

Participating States in This Study

- **Seven states:**
  - **California (CA), Georgia (GA), Missouri (MO), New York (NY), Texas (TX), Virginia (VA), and Wisconsin (WI).**



Bridge Database by State

- **Database Category:**
  - ➢ National Bridge Inventory (NBI)
  - ➢ Long Term Bridge Performance (LTBP) Program

States	Number of Bridges	
	NBI	LTBP
CA	25,771	23
GA	14,940	79
MO	24,494	994
NY	17,540	621
TX	54,432	5
VA	13,933	908
WI	14,249	524

Selection Factors Considered

- Ownership and maintenance responsibility
  - Item 22 = 1 and Item 21 = 1 in NBI
- Service type of the structure
  - Item 42A = 1 or 5 for highway and highway-pedestrian services
- Removal of culverts
  - Item 62 ≠ N
- Number of the bridge span
  - 2 or more
  - Exception made If more candidate bridges are needed in a particular state
- Year of built between 2000 and 2015
- Material type of the structure
  - Item 43A = 3 or 4 for steel girders
  - Item 43A = 5 or 6 for prestressed concrete girders

State Grouping by Material Type

- **Two Groups: Steel and Prestressed Concrete.**

Steel-Girder Bridges	Prestressed Concrete (PC) Girder Bridges
New York	California
Virginia	Georgia
Wisconsin	Texas
Missouri	

- **27 candidate bridges are recommended for each state with an exception of Missouri (54 bridges).**
- **With state DOT inputs, 9 out of 27 bridges will be selected for visual inspection and automated inspections**
- **9 selected bridges are in 3 age groups (5-10, 10-15, and 15-20 years).**

Access to Bridge Sites

- **Bridge candidates should be easily accessed through highway routes.**

FHWA United States National Highway System Routes

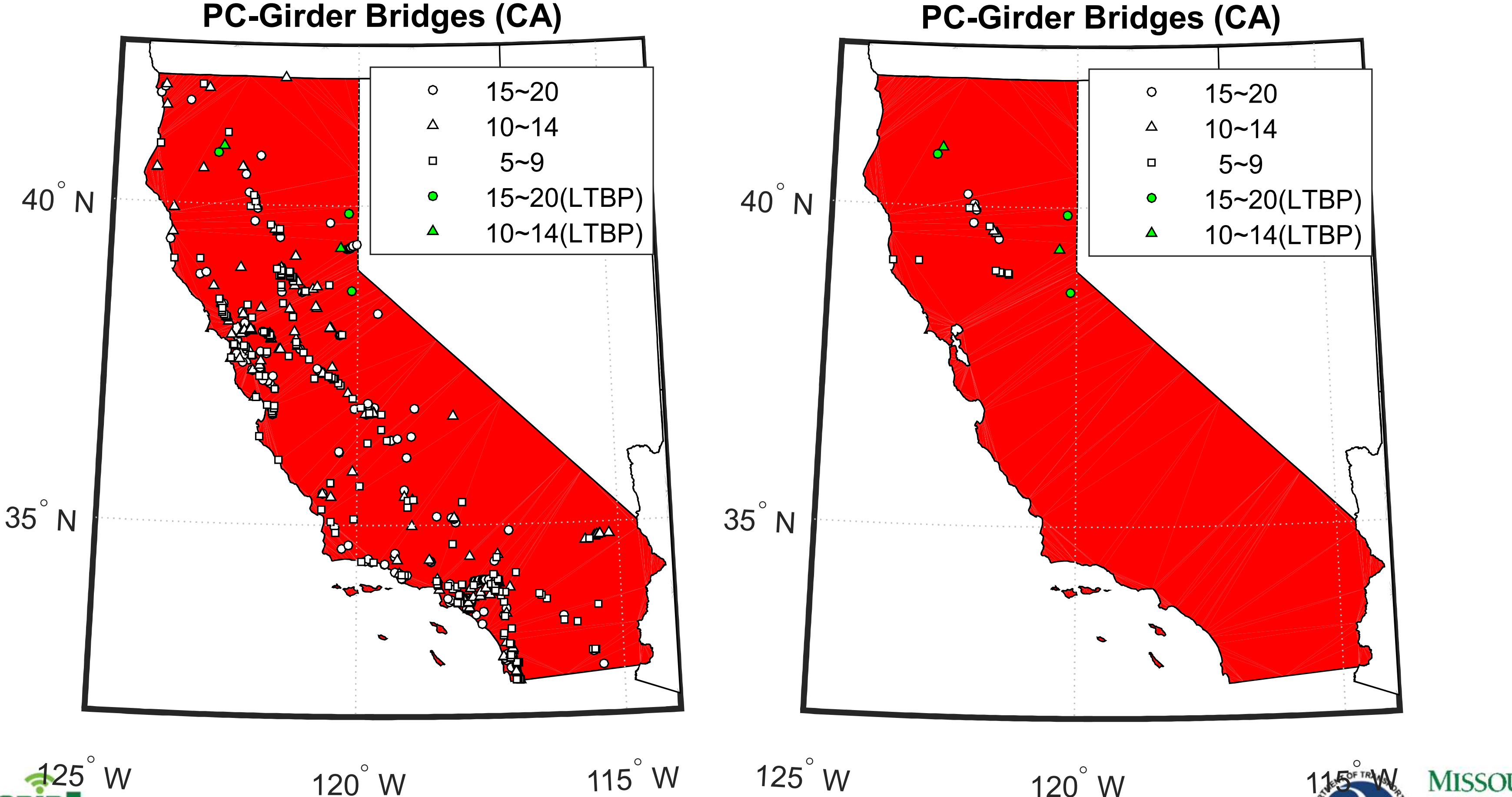
Recommended Bridge Details

- **Sample Bridge Candidates in California**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	STATE_COI	STRUCTURE_I	RECORD_T	ROUTE_PR	SERVICE_L	ROUTE_NU	DIRECTION	HIGHWAY	COUNTY_(	PLACE_CO	FEATURES	CRITICAL_I	FACILITY_(	LOCATION	MIN_VERT	KILOPOINT	BASE_HWY
2	6	' 09 0071 '	1	3	1	284	0	2	63	0	'"LITTLE LA	NaN	'"STATE RC	'"02-PLU-2	99.99	7.01	0
3	6	' 26 0049 '	1	3	1	88	0	10	5	0	'"SILVER LA	NaN	'"STATE RC	'"10-AMA-	99.99	65.82	1
4	6	' 05 0054 '	1	3	1	3	0	2	105	0	'"RUSH CRE	NaN	'"STATE RC	'"02-TRI-0C	99.99	38.73	1
5	6	' 09 0072 '	1	3	1	284	0	2	63	0	'"LITTLE LA	NaN	'"STATE RC	'"02-PLU-2	99.99	7.31	0
6	6	' 12 0193 '	1	3	1	162	0	3	7	54386	'"FEATHER	NaN	'"STATE RC	'"03-BUT-1	99.99	15.57	1
7	6	' 11 0029 '	1	3	1	32	0	3	21	0	'"STONY CI	NaN	'"STATE RC	'"03-GLE-0	99.99	5.23	1
8	6	' 08 0164 '	1	3	1	99	0	2	103	0	'"DEER CRE	NaN	'"STATE RC	'"02-TEH-0	99.99	5.99	1
9	6	' 08 0160 '	1	3	1	99	0	2	103	0	'"MILL CRE	NaN	'"STATE RC	'"02-TEH-0	99.99	13.33	1
10	6	' 08 0157 '	1	4	0	0	0	2	103	0	'"INTERSTA	NaN	'"ADOBE R	'"02-TEH-0	99.99	0	1
11	6	' 17 0075R '	1	1	1	80	0	3	57	0	'"CASTLE P	NaN	'"INTERSTA	'"03-NEV-C	99.99	5.07	1
12	6	' 17 0075L '	1	1	1	80	0	3	57	0	'"CASTLE P	NaN	'"INTERSTA	'"03-NEV-C	99.99	5.07	1
13	6	' 05 0087 '	1	3	1	3	0	2	105	0	'"EAST FOF	NaN	'"SR 3'"	'"02-TRI-0C	99.99	53.69	1
14	6	' 12 0200 '	1	3	1	70	0	3	7	0	'"STATE RC	NaN	'"STATE RC	'"03-BUT-0	6.12	20.53	1
15	6	' 12 0199 '	1	3	7	149	0	3	7	0	'"SR 149 &	NaN	'"S149-E70	'"03-BUT-1	99.99	0.01	0
16	6	' 12 0201 '	1	4	8	0	0	3	7	0	'"STATE RC	NaN	'"PRIVATE	'"03-BUT-1	99.99	0	0
17	6	' 12 0197G '	1	3	7	149	0	3	7	0	'"SR 99 AN	NaN	'"NB 149 T	'"03-BUT-1	99.99	4.8	0
18	6	' 12 0198 '	1	3	1	99	0	3	7	0	'"STATE RC	NaN	'"STATE RC	'"03-BUT-0	99.99	21.73	1
19	6	' 08 0163 '	1	3	1	99	0	2	103	0	'"TOOMES	NaN	'"STATE RC	'"02-TEH-0	99.99	8.38	1
20	6	' 19 0201 '	1	4	6	0	0	3	61	0	'"STATE RC	NaN	'"NORTH F.	'"03-PLA-0	99.99	0	0
21	6	' 19 0198R '	1	3	1	65	0	3	61	0	'"BIG YANK	NaN	'"STATE RC	'"03-PLA-0	99.99	22.25	1
22	6	' 18 0001R '	1	3	1	70	0	3	101	0	'"BEAR RIV	NaN	'"STATE RC	'"03-SUT-0	99.99	8.09	1
23	6	' 16 0051 '	1	4	1	0	0	3	115	0	'"STATE RC	NaN	'"FEATHER	'"03-YUB-0	99.99	0	0
24	6	' 18 0051 '	1	3	1	113	0	3	101	0	'"STATE RC	NaN	'"STATE RC	'"03-SUT-1	99.99	16.35	1
25	6	' 10 0156 '	1	3	1	1	0	1	45	0	'"GREENW	NaN	'"STATE RC	'"01-MEN-	99.99	33.63	1
26	6	' 10 0301 '	1	3	1	222	0	1	45	0	'"RUSSIAN	NaN	'"STATE RC	'"01-MEN-	99.99	0.98	0
27	6	' 12 0126R '	1	3	1	99	0	3	7	0	'"BUTTE CR	NaN	'"STATE RC	'"03-BUT-0	99.99	28.72	1
28	6	' 08 0165 '	1	1	1	5	0	2	103	0	'"THOMES	NaN	'"INTERSTA	'"02-TEH-0	99.99	12.16	1

PC-Girder Bridges (California)

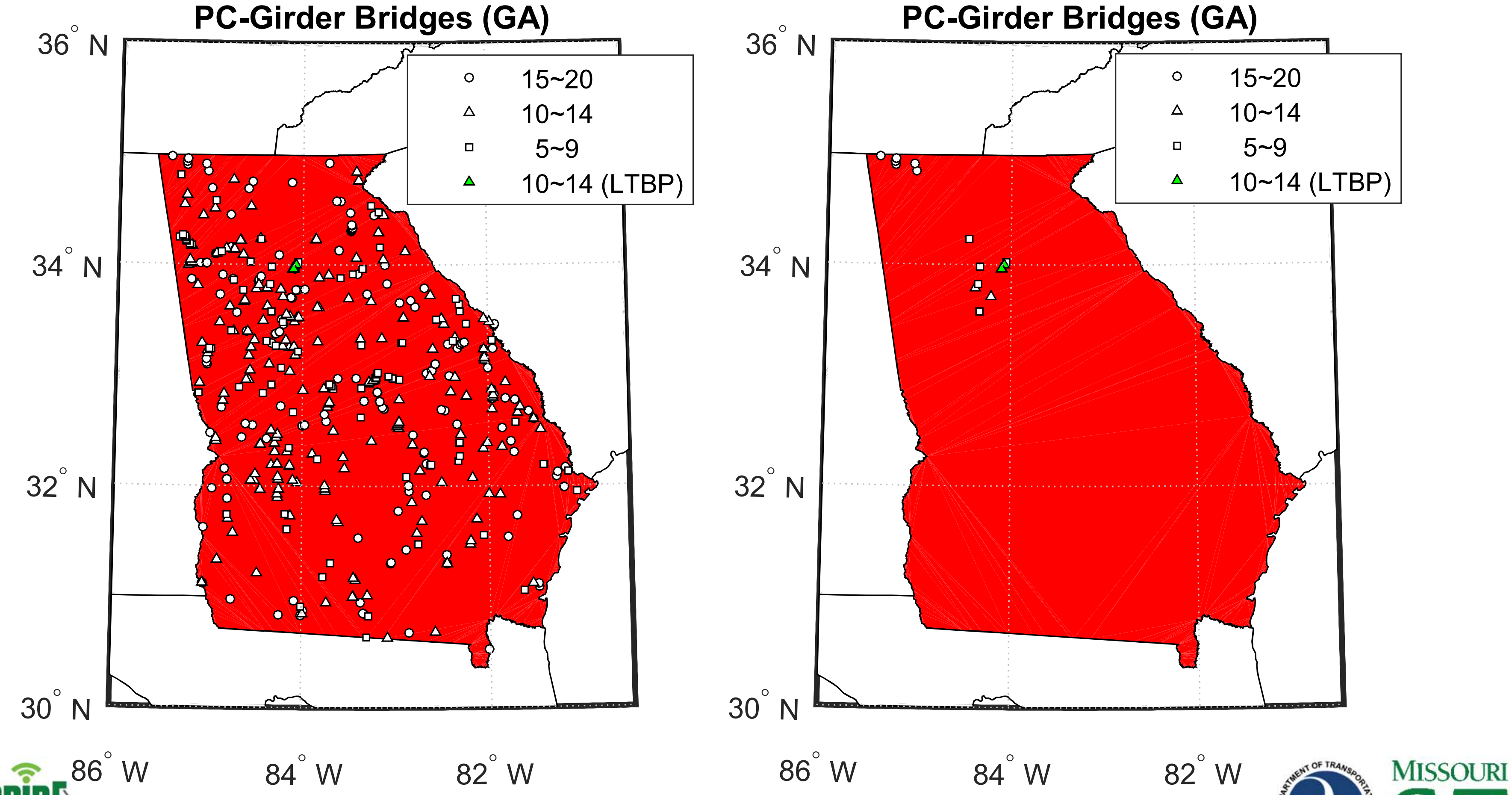
- **Candidates: NBI - 371 (oldest), 226, and 258 (newest), including 4, 3, and 0 suggested by LTBP Program**
- **Recommendation: NBI - 5, 6, 9; LTBP - 4, 3, 0**



(a) All candidates (b) Recommendation

PC-Girder Bridges (Georgia)

- Candidates: NBI – 212 (oldest), 234, and 114 (newest), including 0, 6, and 0 suggested by LTBP Program
- Recommendation: NBI - 9, 3, 9; LTBP - 0, 6, 0

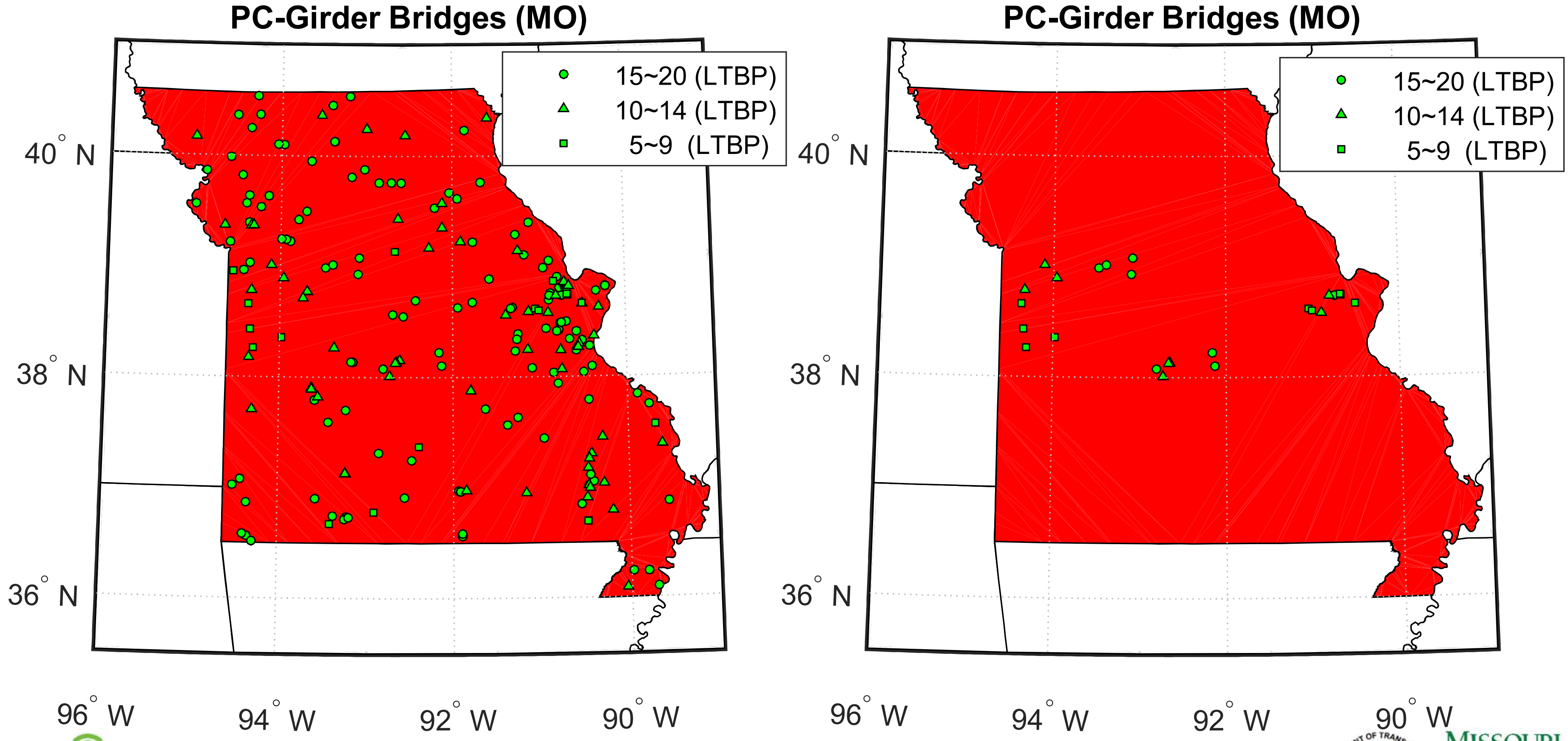


(a) All candidates

(b) Recommendation

PC-Girder Bridges (Missouri)

- **Candidates: NBI – 314 (oldest), 402, 553 (newest), including 155, 69, and 18 suggested by LTBP Program**
- **Recommendation: NBI - 0, 0, 0; LTBP - 9, 9, 9**



(a) All candidates (b) Recommendation

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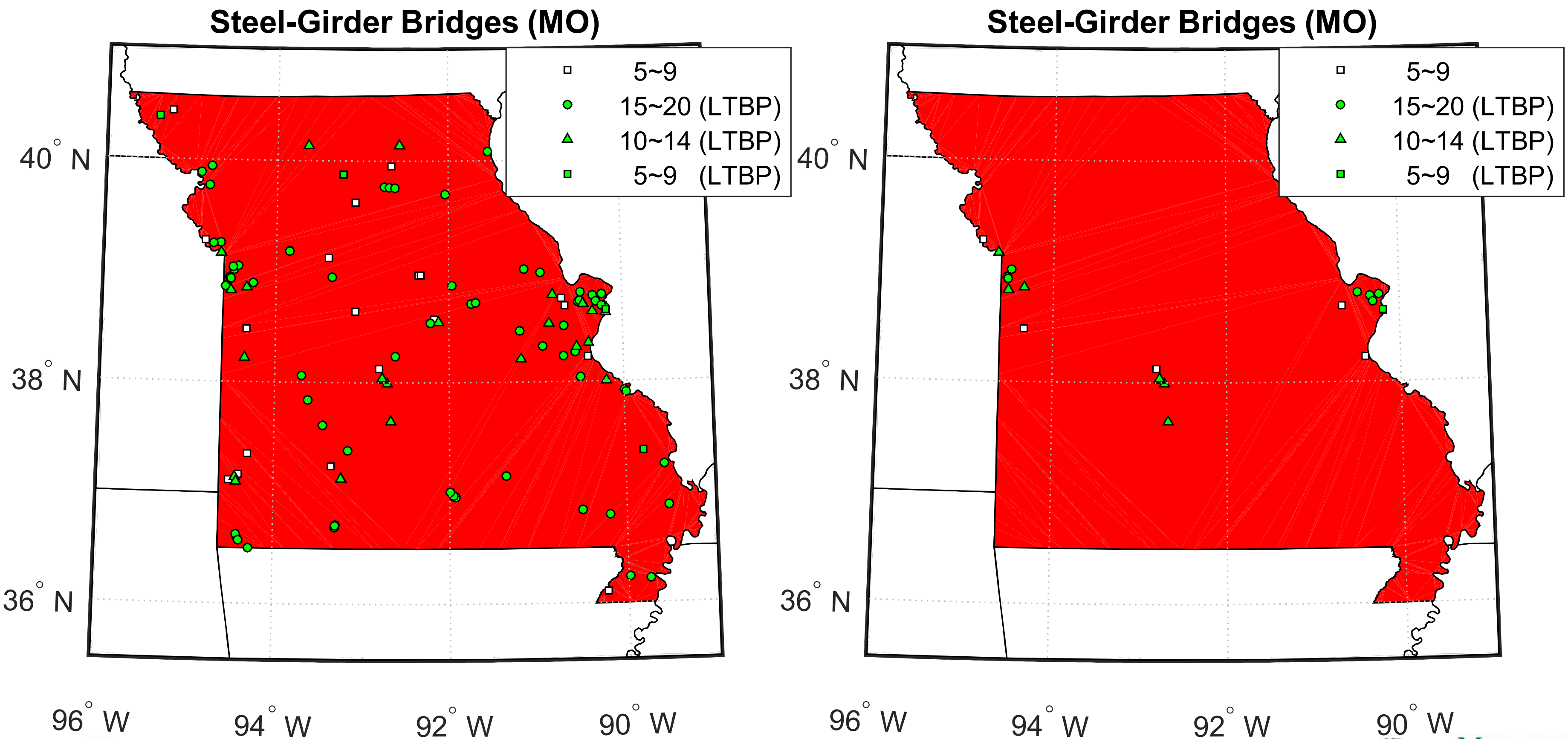
Steel-Girder Bridges (Missouri)

- **Candidates: NBI – 179 (oldest), 64, and 27 (newest), including 84, 29, and 5 suggested by LTBP Program**
- **Recommendation: NBI - 0, 0, 7; LTBP - 9, 9, 2**

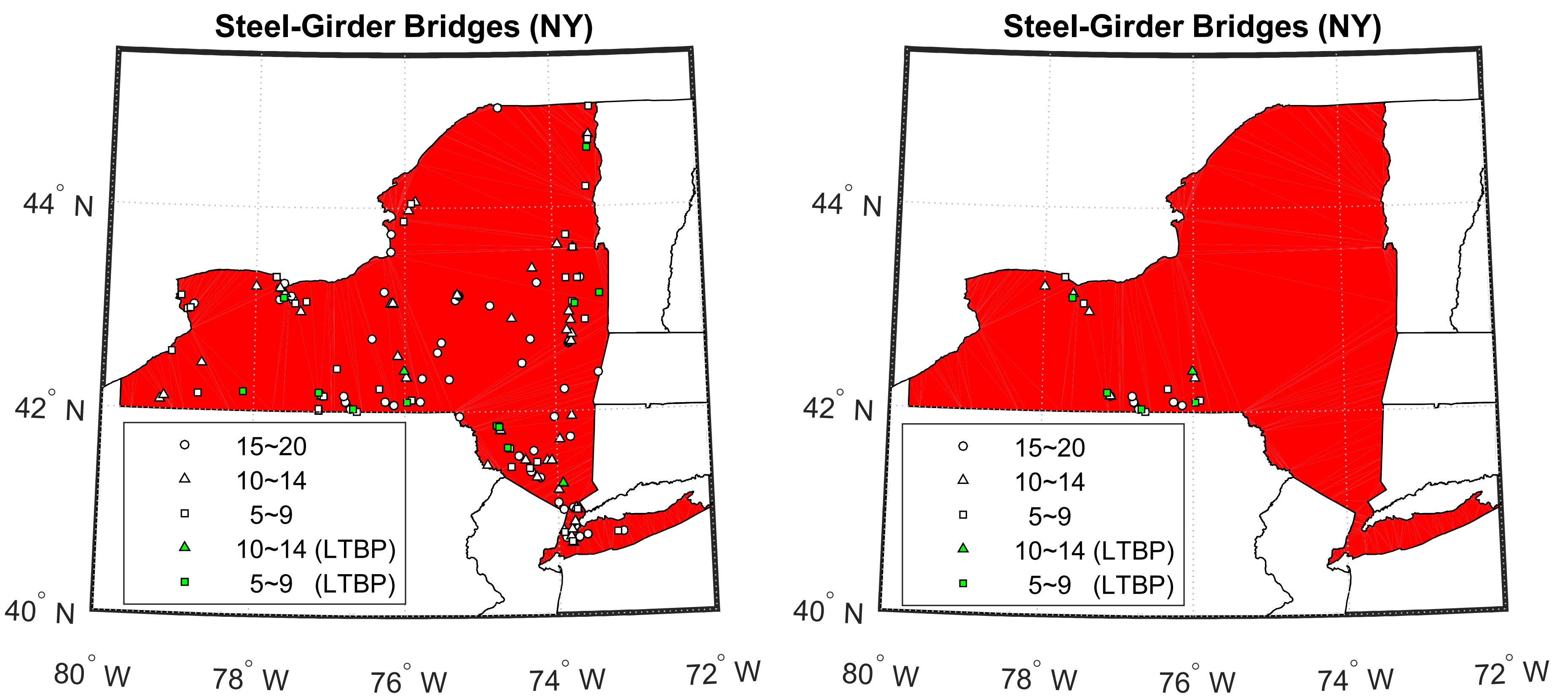


(a) All candidates

(b) Recommendation

Steel-Girder Bridges (New York)

- **Candidates: NBI – 65 (oldest), 64, and 47 (newest), including 0, 2, 14 suggested by LTBP Program**
- **Recommendation: NBI - 9, 8, 5; LTBP - 0, 1, 4**

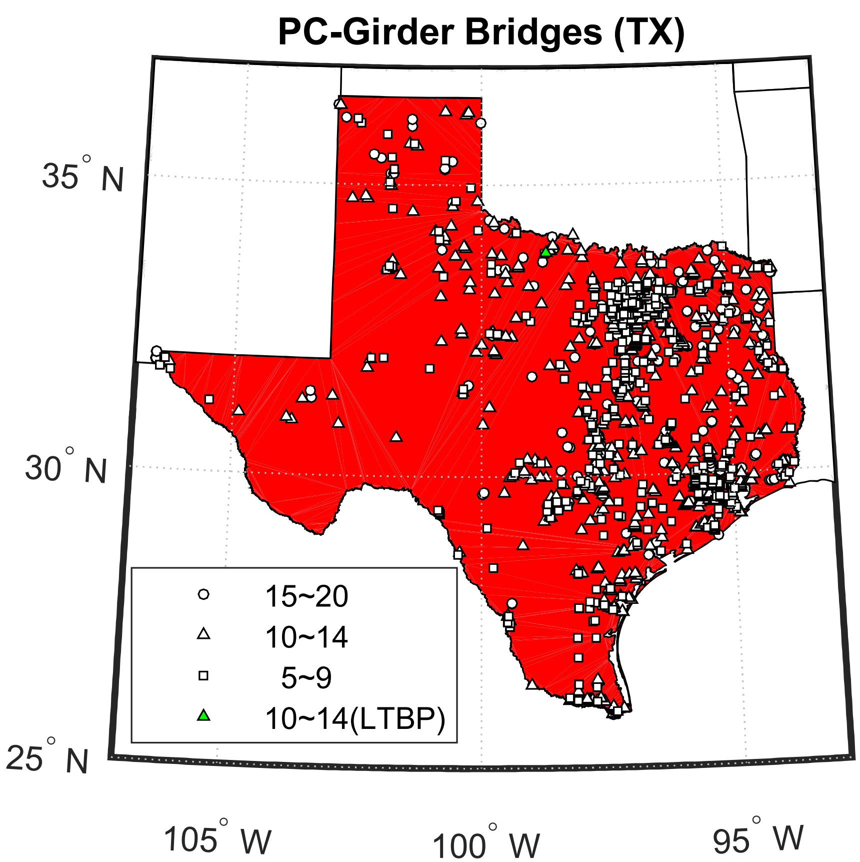


(a) All candidates

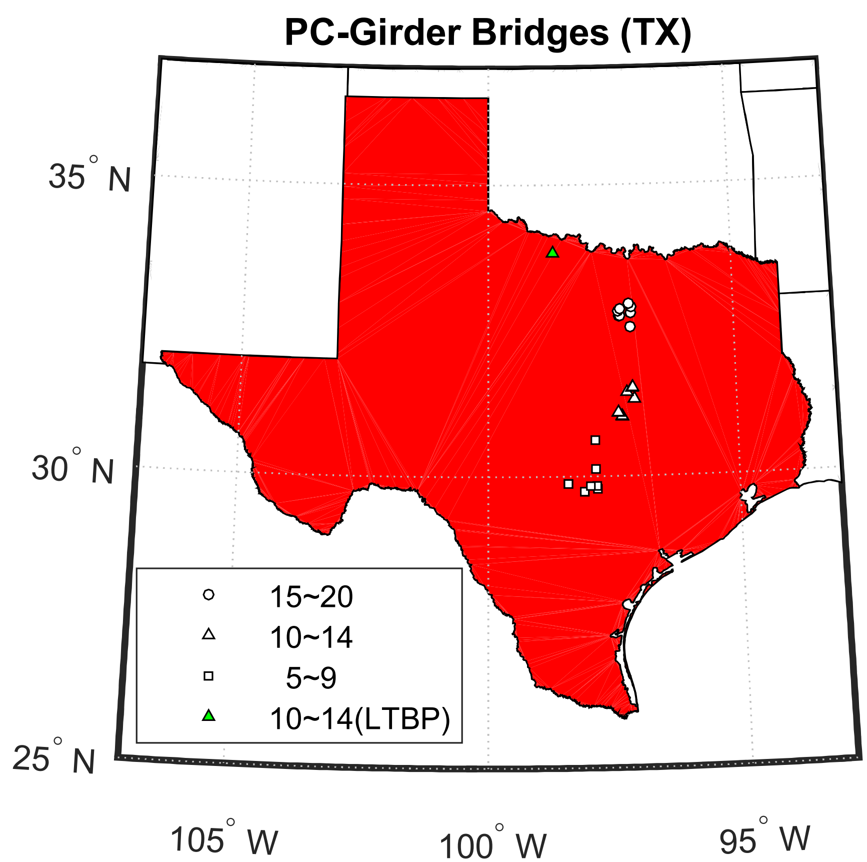
(b) Recommendation

PC-Girder Bridges (Texas)

- Candidates: NBI – 334 (oldest), 791, and 607 (newest) including 0, 1, and 0 suggested by LTBP Program
- Recommendation: NBI - 9, 8, 9; LTBP - 0, 1, 0



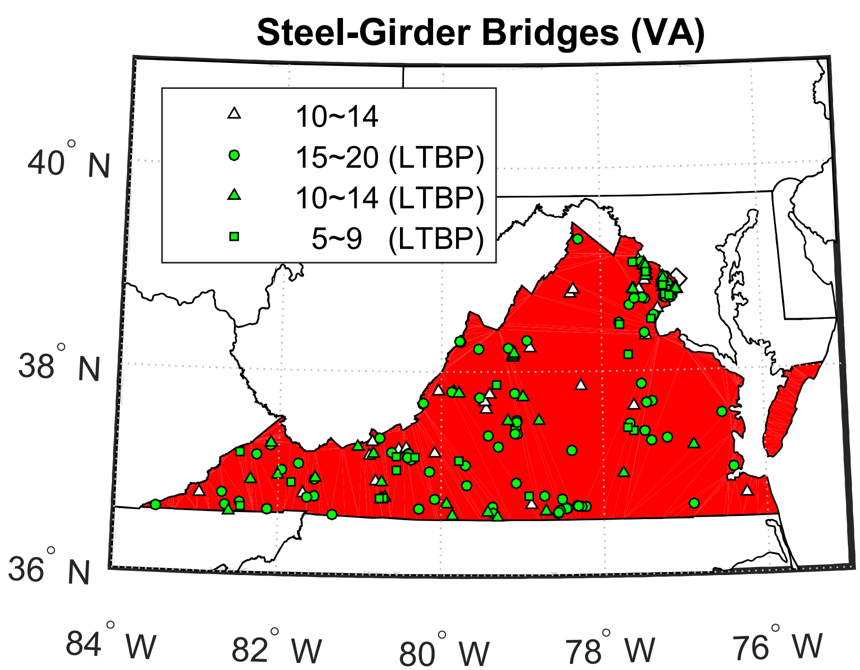
(a) All candidates



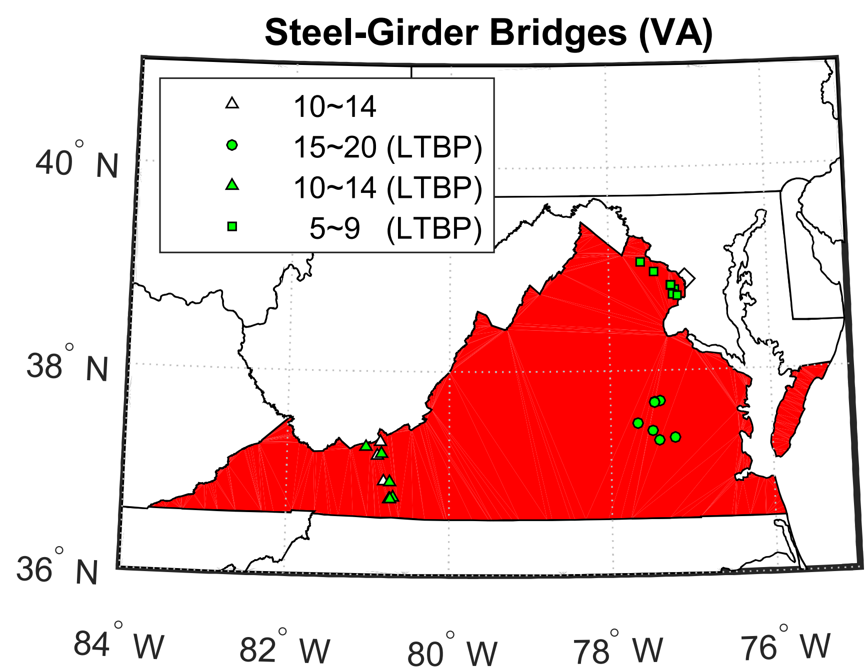
(b) Recommendation

Steel-Girder Bridges (Virginia)

- Candidates: NBI – 116 (oldest), 63, and 41 (newest), including 114, 38, and 28 suggested by LTBP Program
- Recommendation: NBI - 0, 4, 0; LTBP - 9, 5, 9



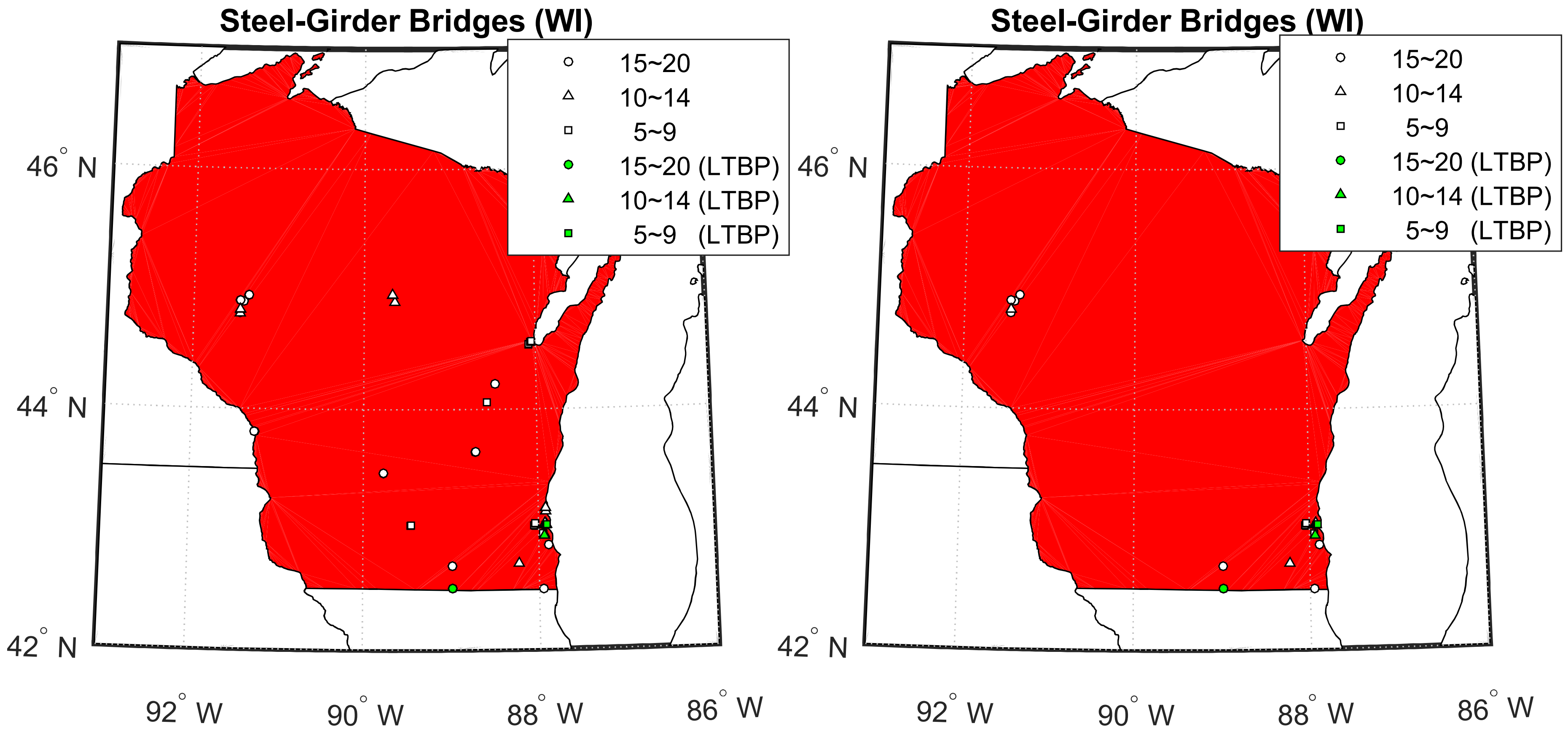
(a) All candidates



(b) Recommendation

Steel-Girder Bridges (Wisconsin)

- **Candidates: NBI – 18 (oldest), 33, and 22 (newest), including 2, 1, 1 suggested by LTBP Program**
- **Recommendation: NBI - 7, 8, 8; LTBP - 2, 1, 1**



(a) All candidates

(b) Recommendation

Action Items

- Dr. Chen will send 27 bridges selected to each state DOT (MoDOT will receive 54 bridges) soon after this meeting.
- Two approaches will be used to finalize bridges to be tested
  - Each DOT can finalize 3 bridges in each age group and send bridge drawings to Dr. Chen
  - Each DOT can send 27 bridge drawings to Dr. Chen for a final selection of 9 bridges in three age groups
- Each DOT will help conduct visual inspection for comparison with robot-assisted inspection with NDE and remote sensing. Dr. Chen's team will coordinate with a DOT representative in each participating state for field works.

Concluding Remarks

- An autonomous inspection platform can help inspect and maintain bridges in a faster, saver, cheaper and more consistent manner.
- Advanced technologies required to realize the autonomous inspection platform are being developed in the INSPIRE University Transportation Center.
- This pooled-fund initiative can help develop case studies, protocols, and guidelines that can be adopted by state DOTs for bridge inspection and maintenance.

Acknowledgement

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- The views, opinions, findings and conclusions reflected in this publication are solely those of the authors and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.