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Center for Advanced Infrastructure and Transportation

Center for Advanced Infrastructure and Transportation (CAIT)

A University Transportation Center

Improving Bridge Assessment, Prognosis, and Interventions through Emerging Technology

Presented by

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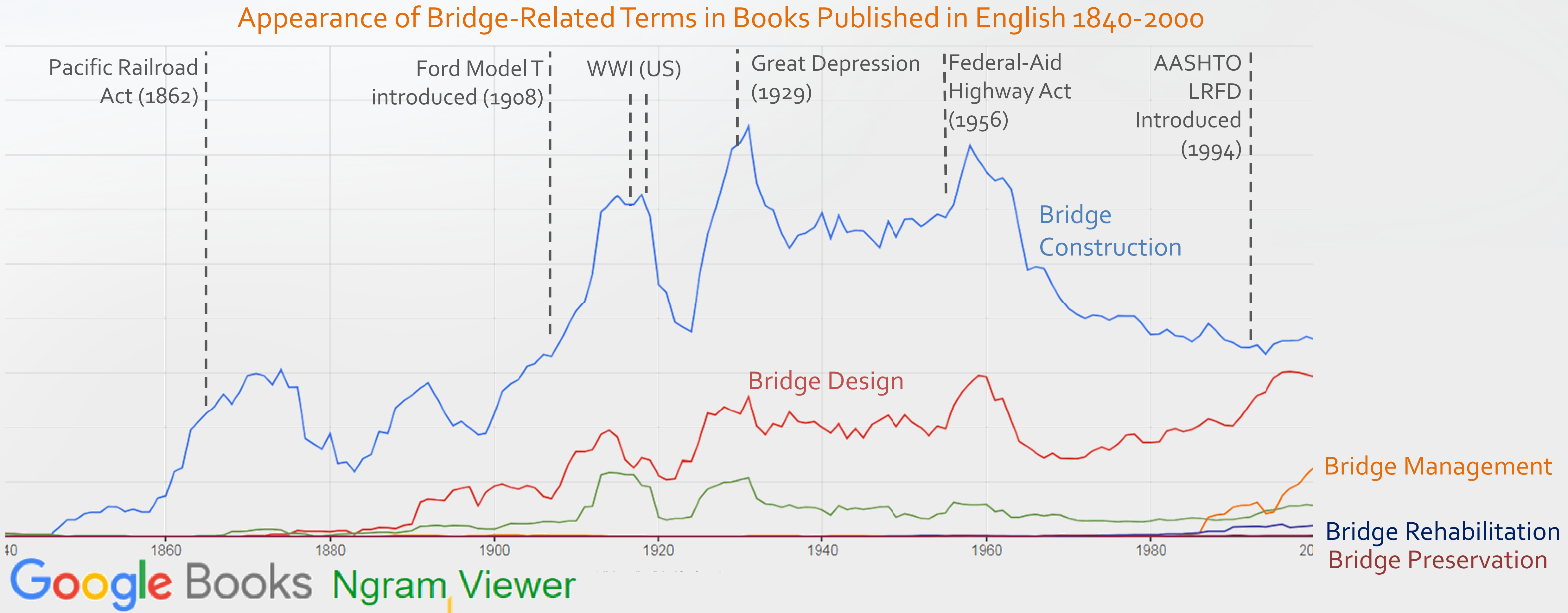
Motivation…

Some Critical, Open (and billion dollar) Questions

- What are the primary factors that lead to poor bridge durability and how do they interact with one another?
  - Construction techniques, quality? Structural characteristics, design details? Environmental inputs? Live load? De-icing agents? Others?
- What are the best practice design and maintenance actions to ensure good long-term bridge performance?
- What are the most reliable techniques to identify and predict the onset of deterioration?
- What are the best practices to mitigate deterioration once it has initiated, and when is the optimum time to apply them?

Usage of Bridge-Related Terms

…as a surrogate for perceived importance, knowledge



Structuring Bridge Performance

Key goal of bridge performance research

- Live load
- Environmental inputs
- Maintenance
- Preservation

…

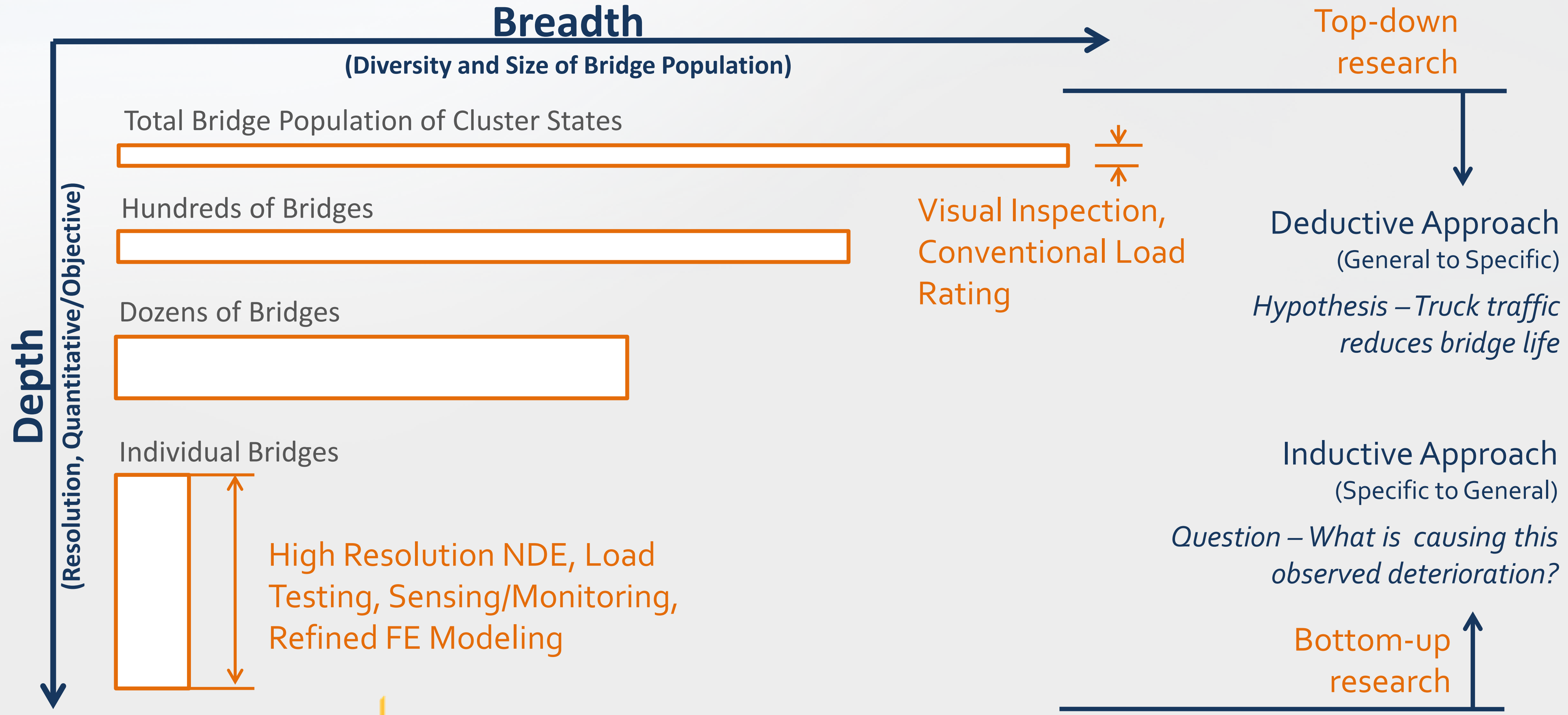
***f*(Attributes, Inputs) = Bridge Performance**

- Age/time
- Design details
- Materials
- Structural Characteristics
- Construction Quality

…

Structural Safety
Serviceability and Durability
Functionality and Utility
Cost
…

Approaches to Studying Bridge Performance



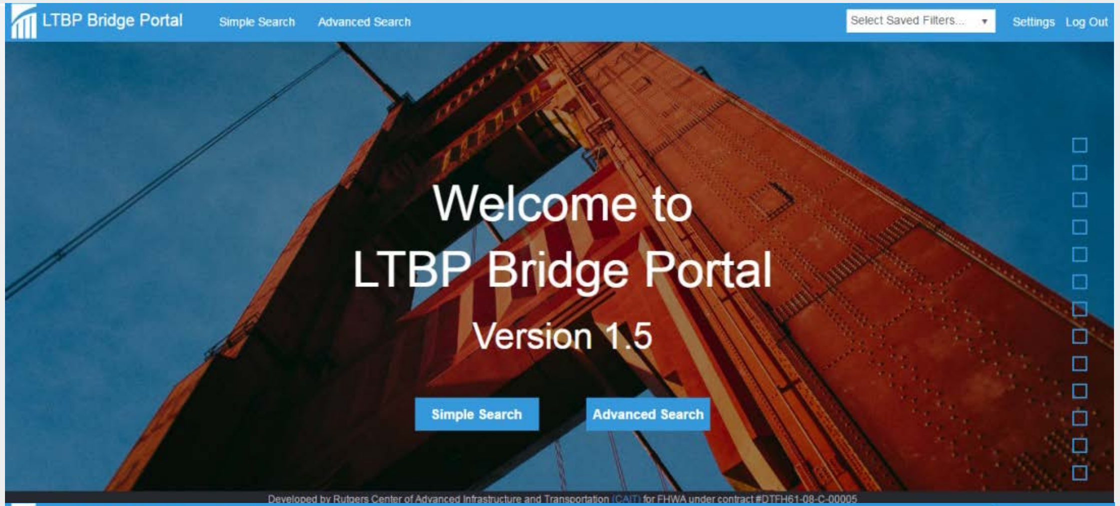
Top-Down Approaches to Studying Bridge Performance

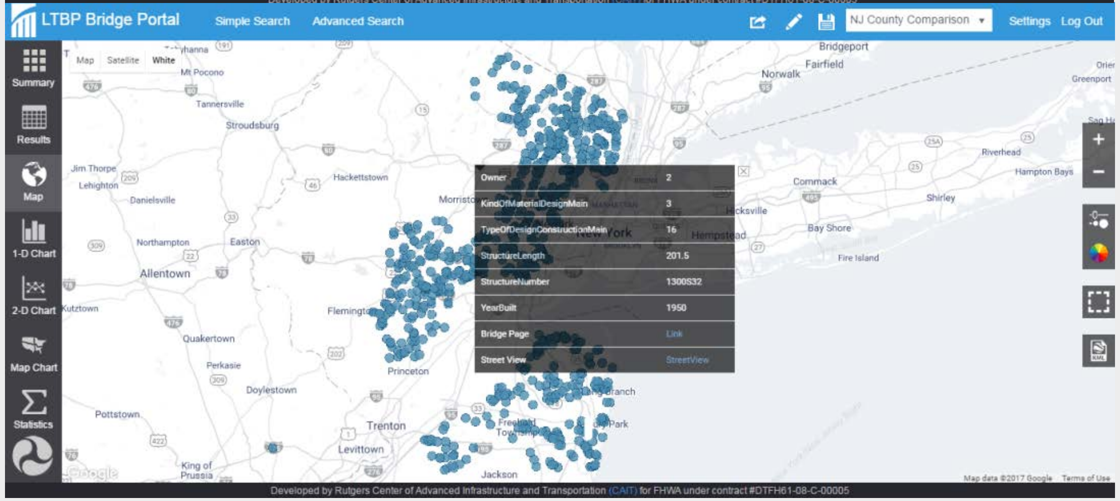
Example, Available Data Sources

- National Bridge Inventory (NBI) (1992 – 2016)
  - Historical Condition Data
  - Historical Traffic Data
- Element Level Inspection (~1997 – 2014)
- Environmental Data (1992 – 2016)
  - No. of snowfalls
  - No. of freeze-thaw cycles

Example Tools

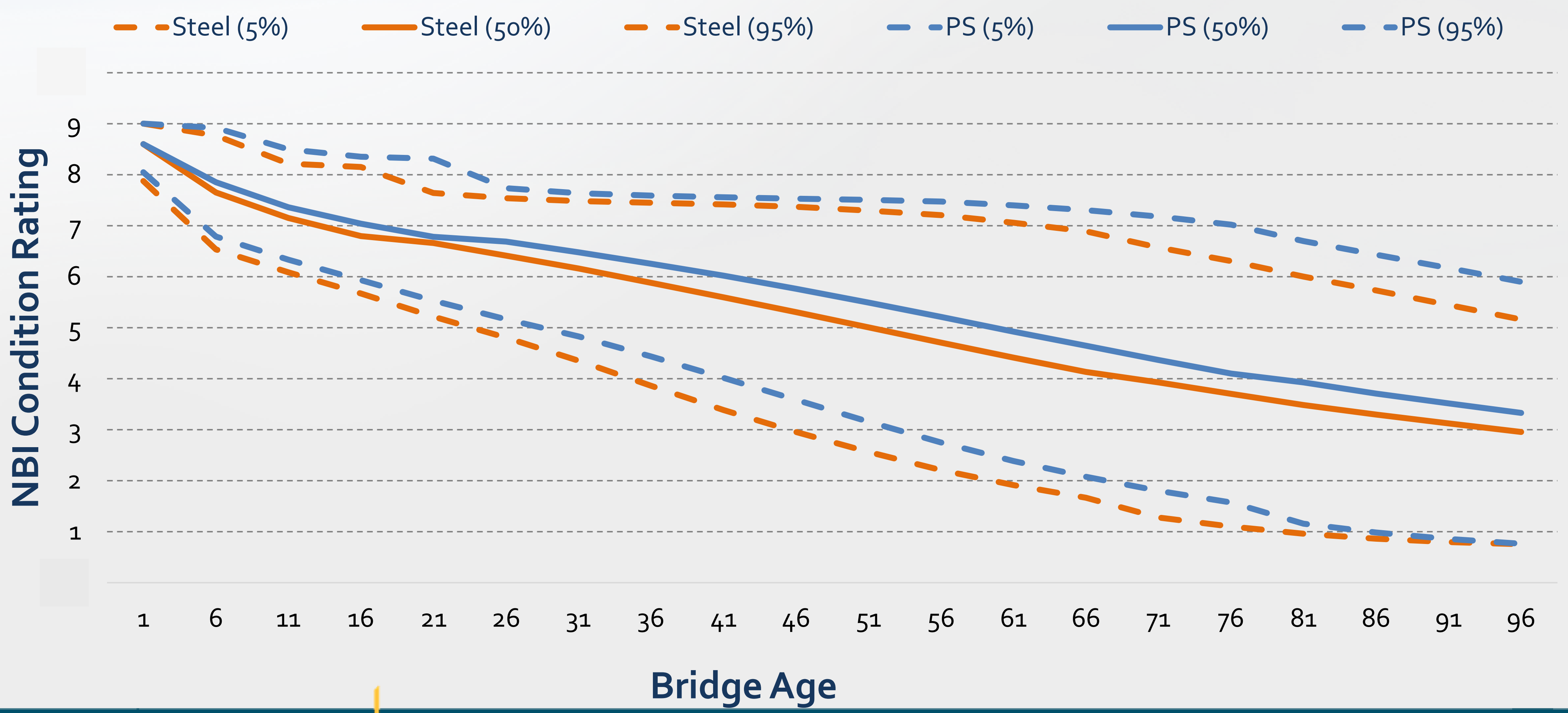
- Graphical Information Systems
- Probabilistic Models
  - Markov
  - Weibull
- Machine Learning
  - Is fundamentally data driven – generates models directly from input-output data
  - Does not rely on explicit, static programming





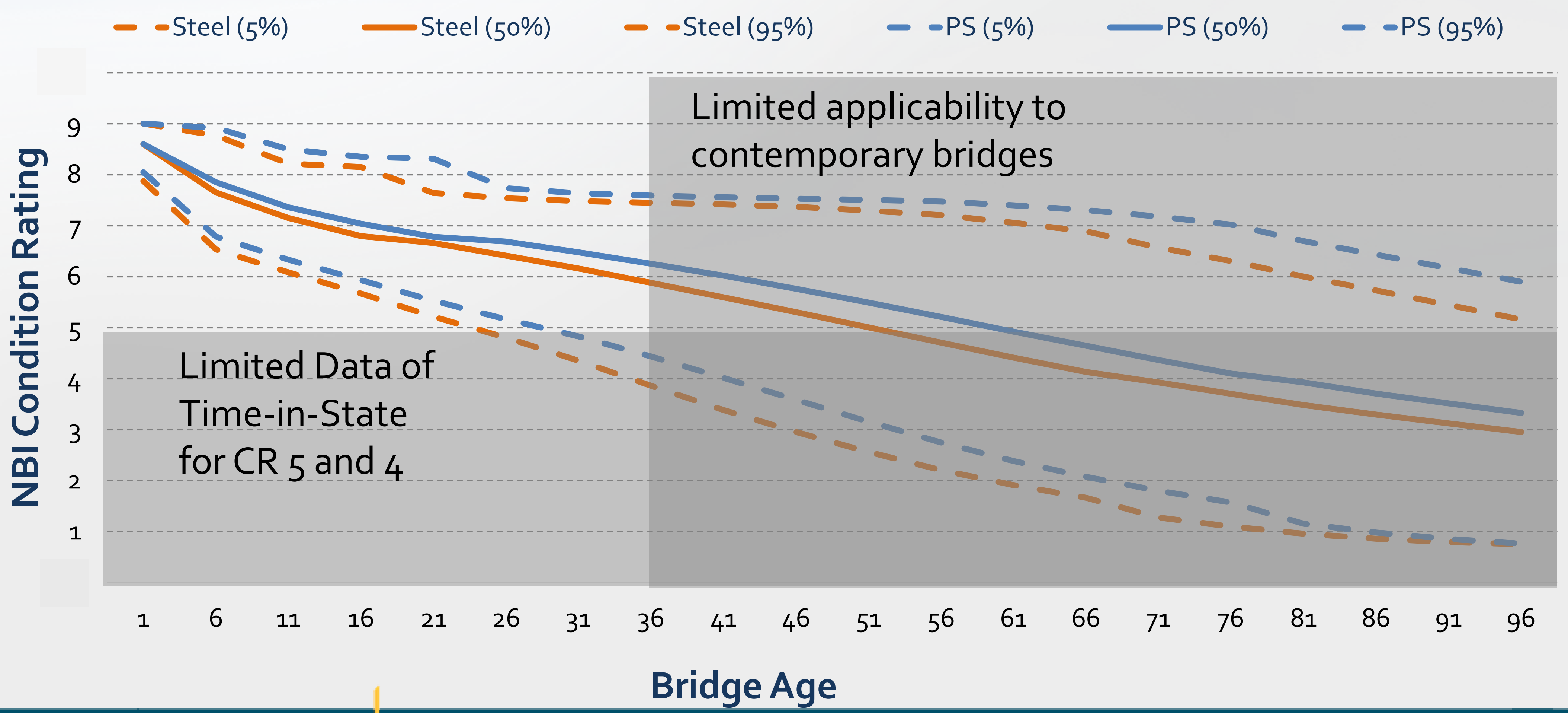
Variability of Resulting Deterioration Models

Deterioration Modeling (Weibull) – Mid-Atlantic Cluster



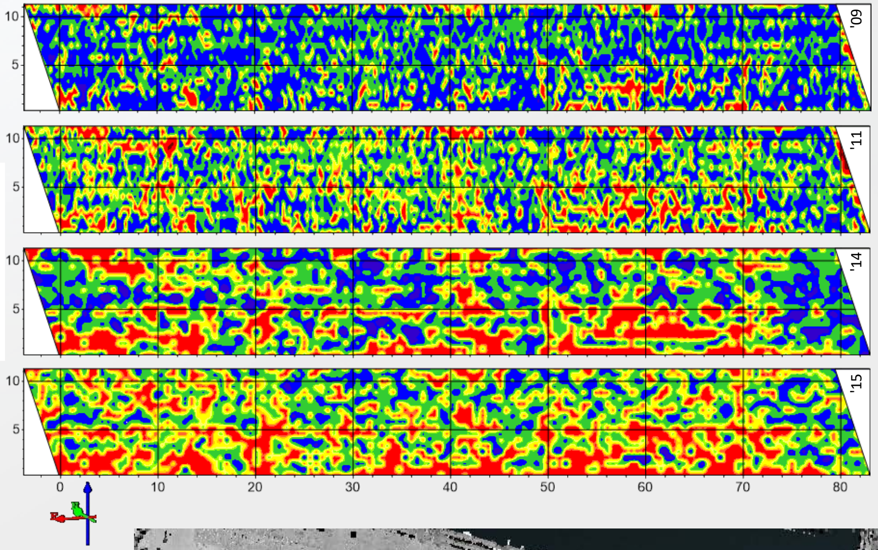
Fundamental Limitations of Top-down Studies

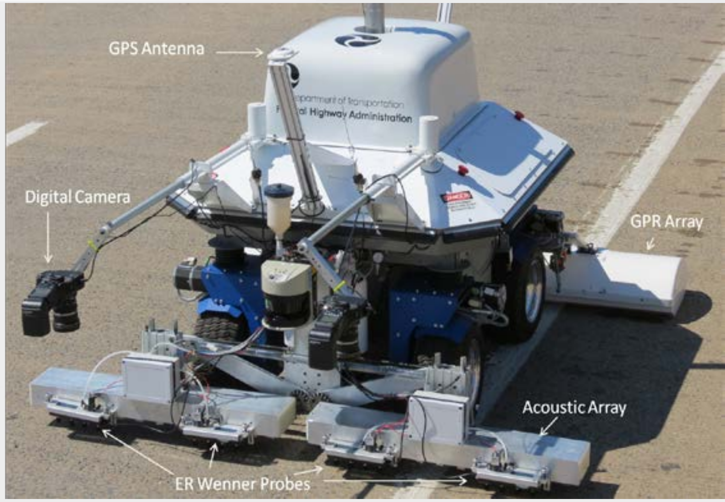
Deterioration Modeling (Weibull) – Mid-Atlantic Cluster

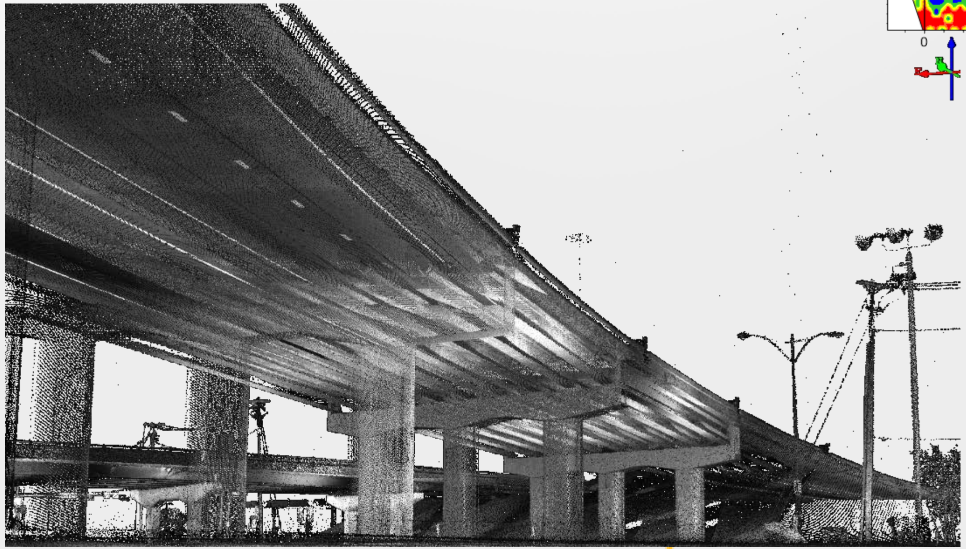


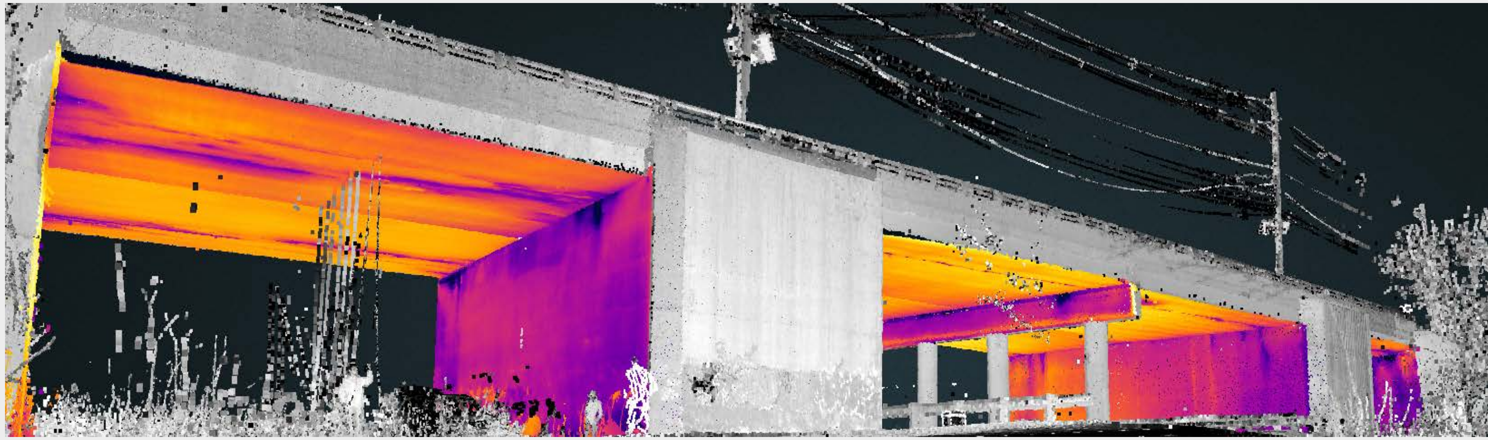
Example Bottom-up Approaches

Nondestructive Evaluation, Sensing and Monitoring, Remote Sensing





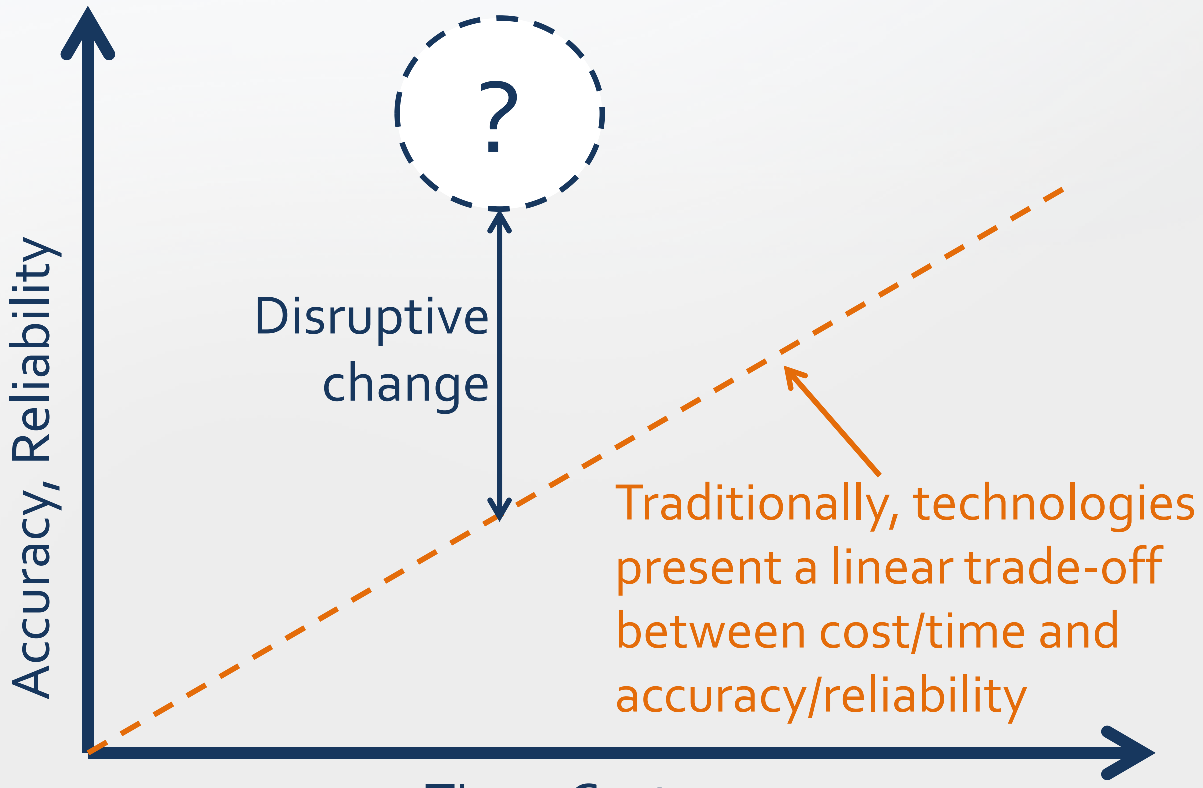




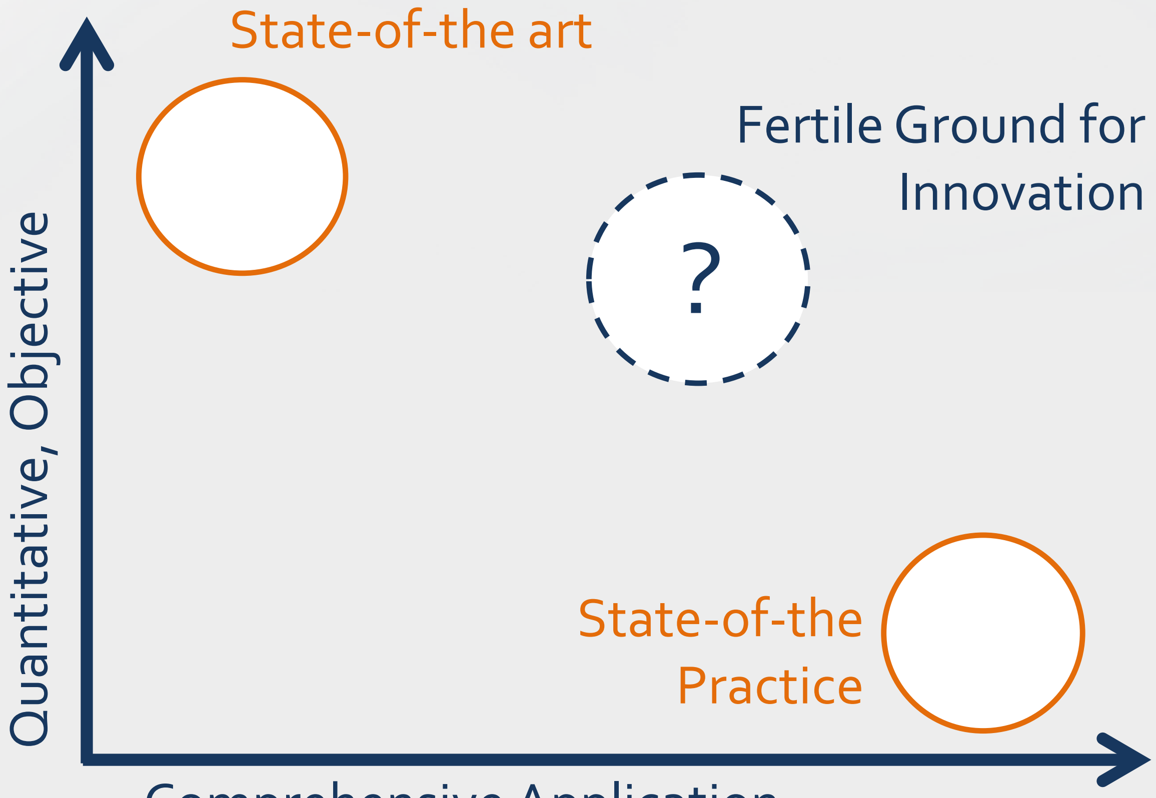
Direction of Bottom-up Approaches

Cost, Time, Accuracy – Pick Two

Perspective 1



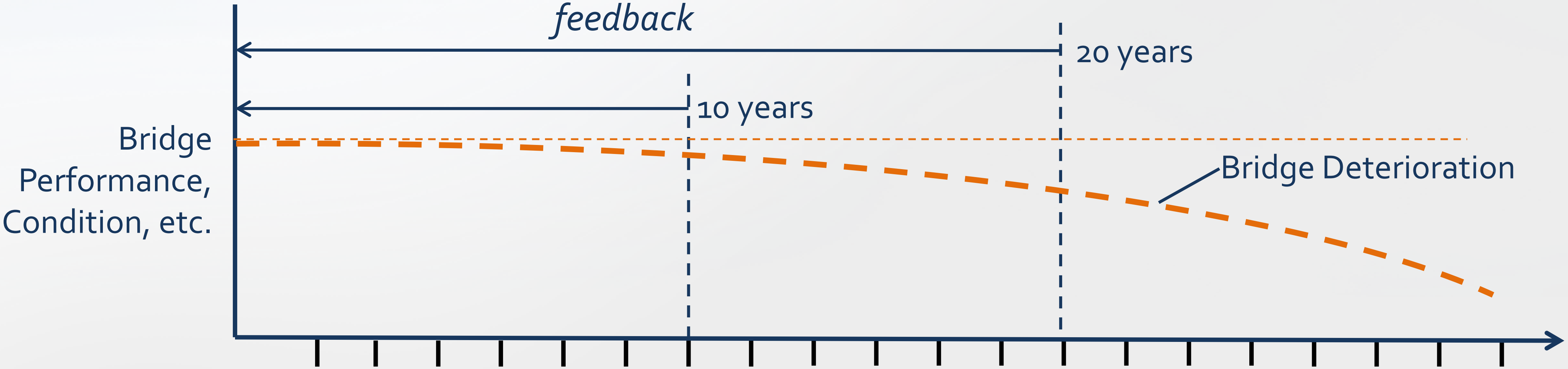
Perspective 2



Synergies Between Research Strategies

Understanding bridge performance requires…	…quantitative, objective data	…across large populations of bridges…	…in a timely manner.
Top-down Approaches			
Bottom-up Approaches			

Principal Challenge – Slow Feedback Loop



The long-durations of the current feedback loop are stifling innovation

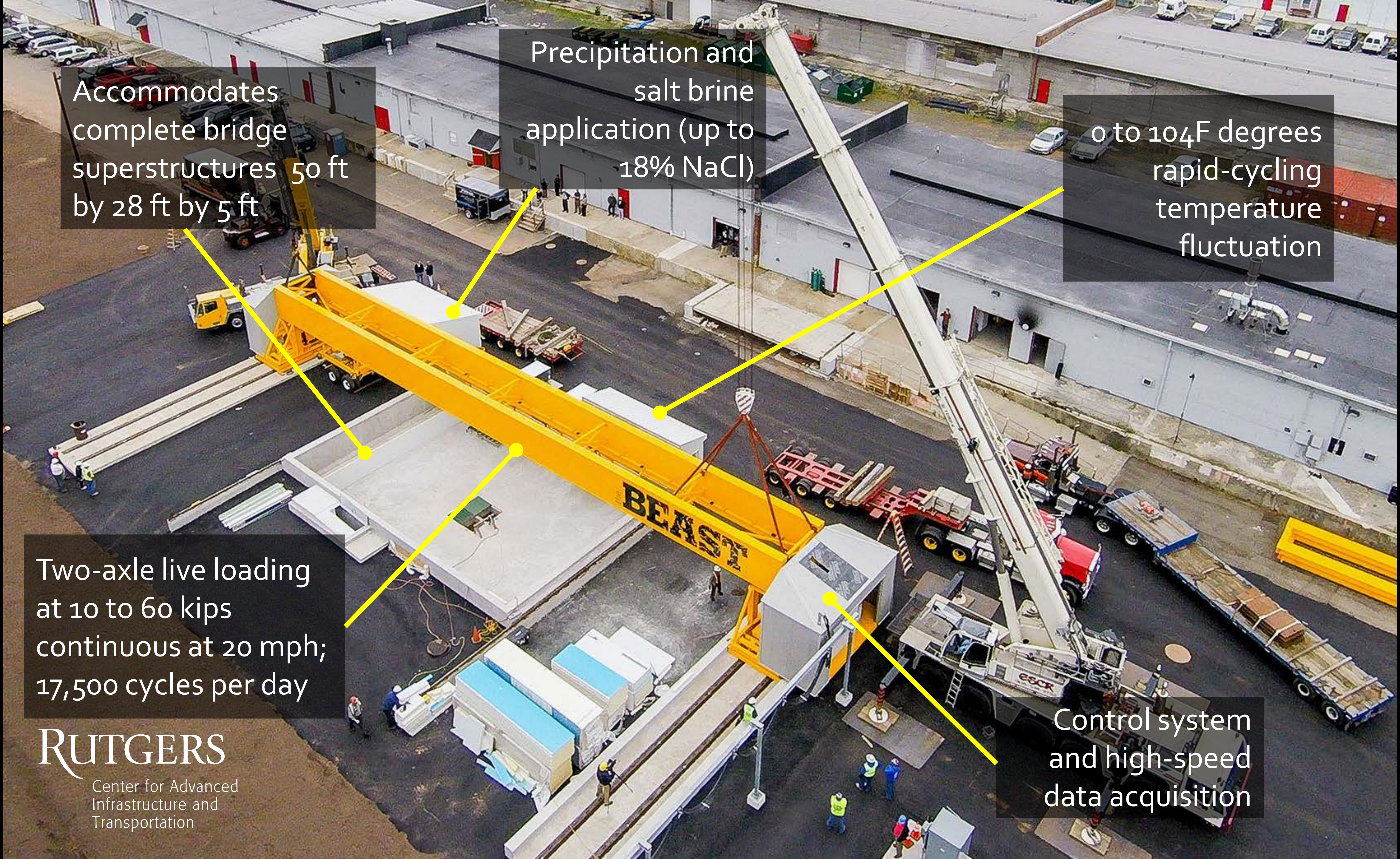
Best Cell Phone (2007)
"Offers everything you
could want in a cell phone"
-PC World

AT&T Phone (1997)
Big Breakthrough…
- Internal antenna

Bridge Evaluation and Accelerated Testing (BEAST) Laboratory

Accelerate deterioration in a realistic manner through the application of live load, environmental, and maintenance demands on full-scale bridge superstructures to enable…

- ***Perform longitudinal studies*** to observe the full life cycle of bridge performance (deterioration, initiation, and propagation) in a highly condensed time, and quantify the performance through high-resolution (both spatial and temporal) data collection efforts
- ***Perform comparative studies*** that aim to establish the relative influences on long-term bridge performance of competing materials, construction practices, design details, and preservation/maintenance actions.
- ***Decouple influences*** associated with different demands on various deterioration processes of bridges through controlling the levels of live load, environmental, and maintenance exposure


Accommodates complete bridge superstructures 50 ft by 28 ft by 5 ft
Precipitation and salt brine application (up to 18% NaCl)
0 to 104F degrees rapid-cycling temperature fluctuation
BEAST
Two-axle live loading at 10 to 60 kips continuous at 20 mph; 17,500 cycles per day
Control system and high-speed data acquisition
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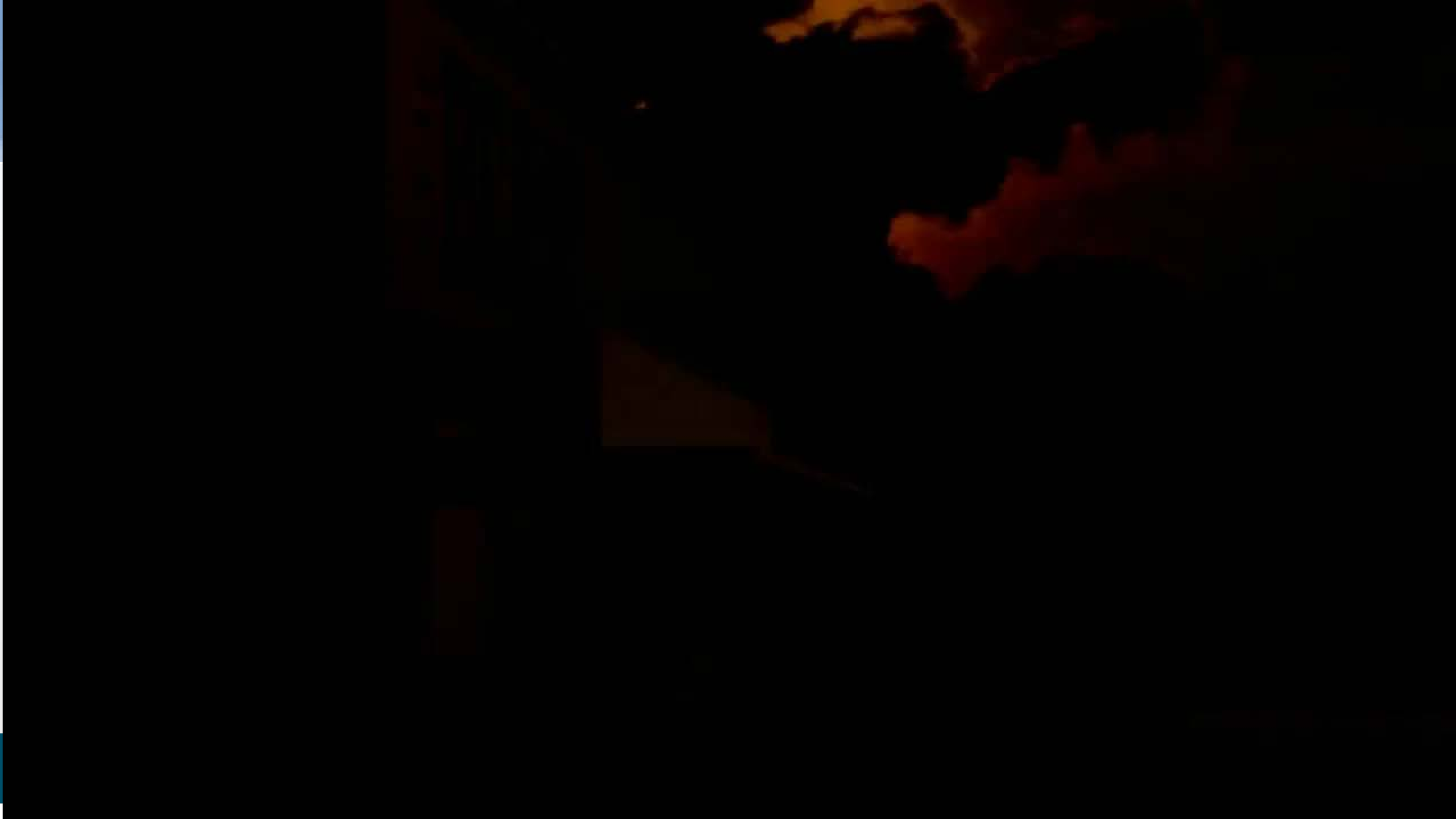
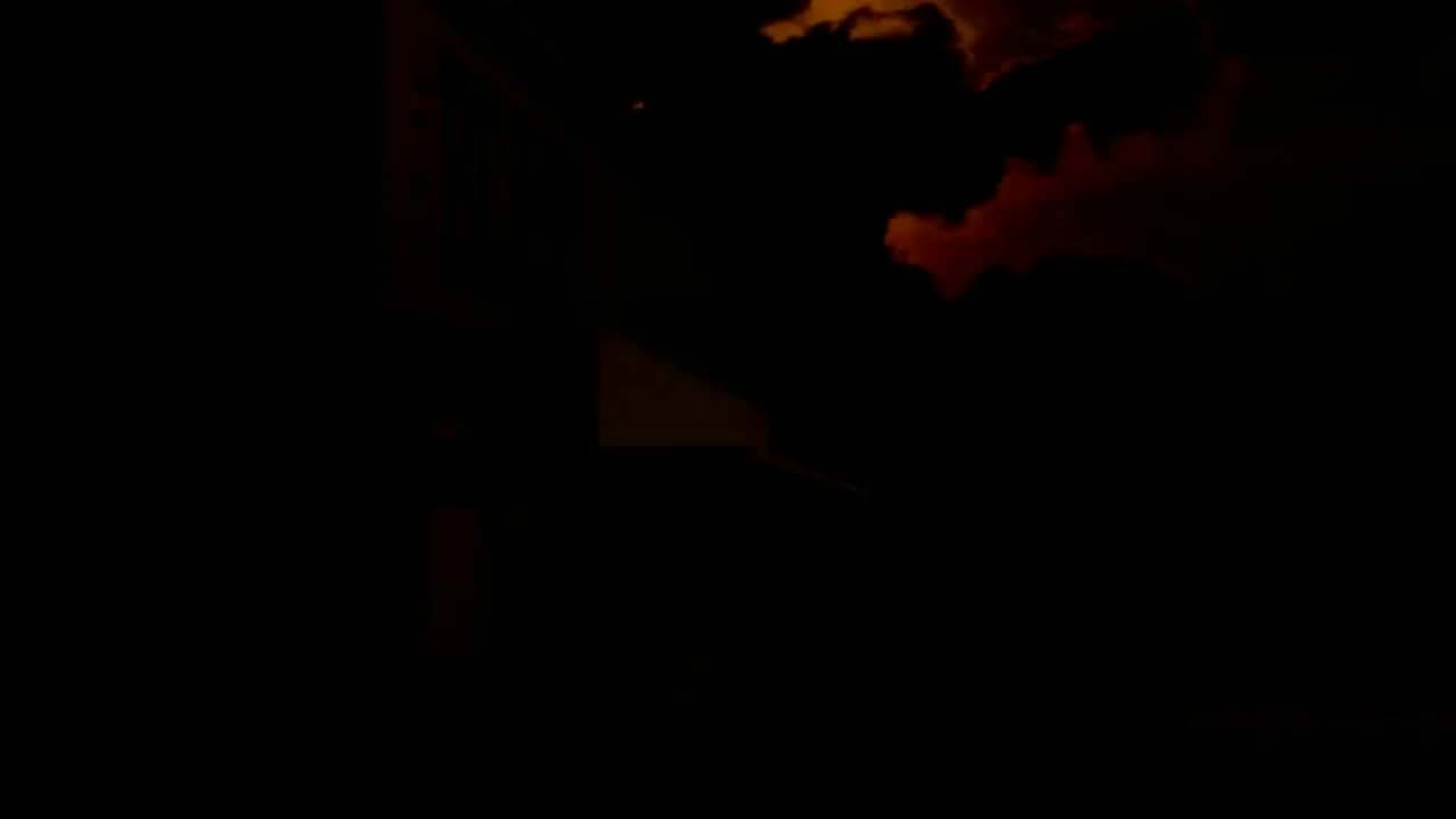
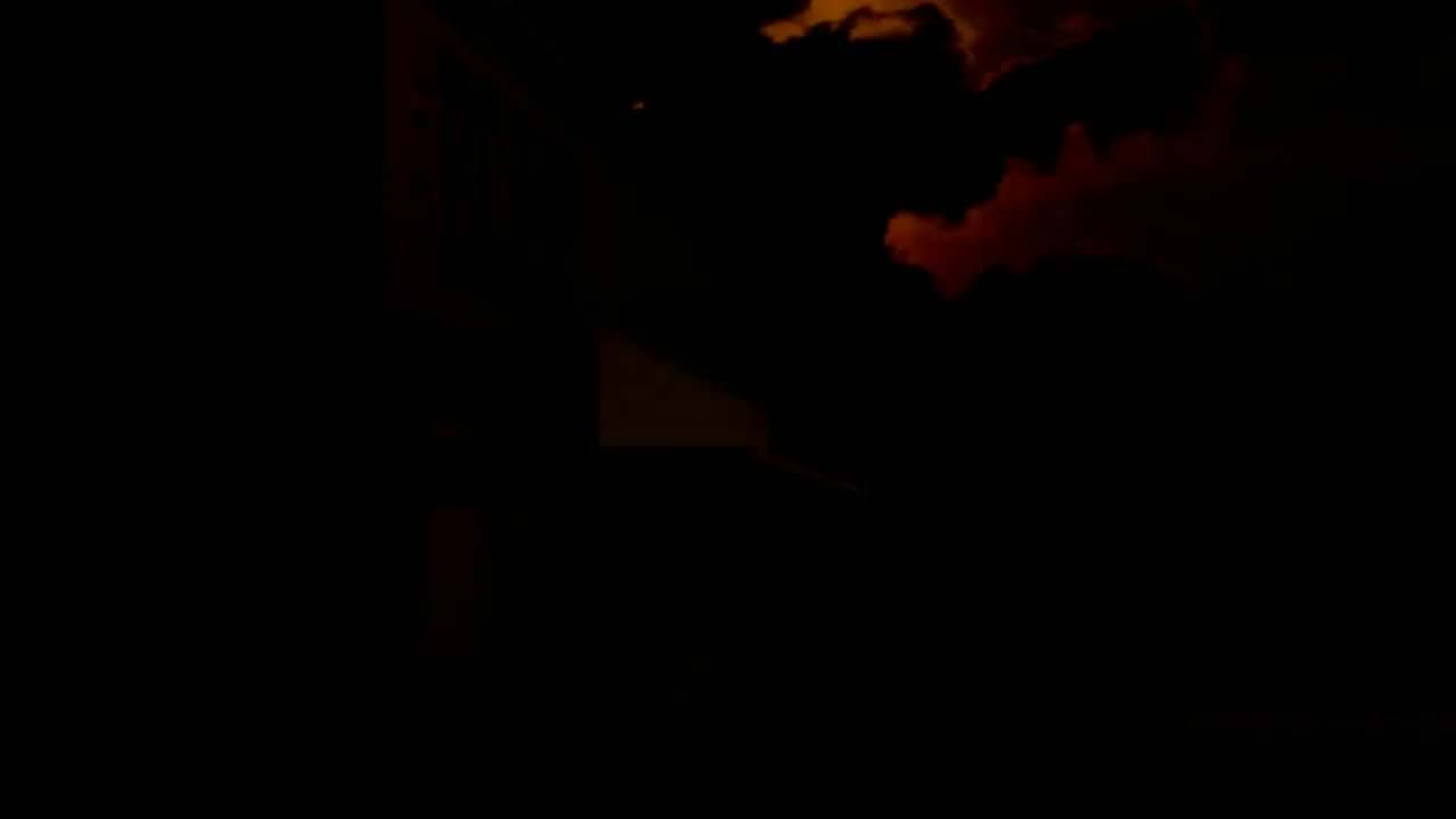
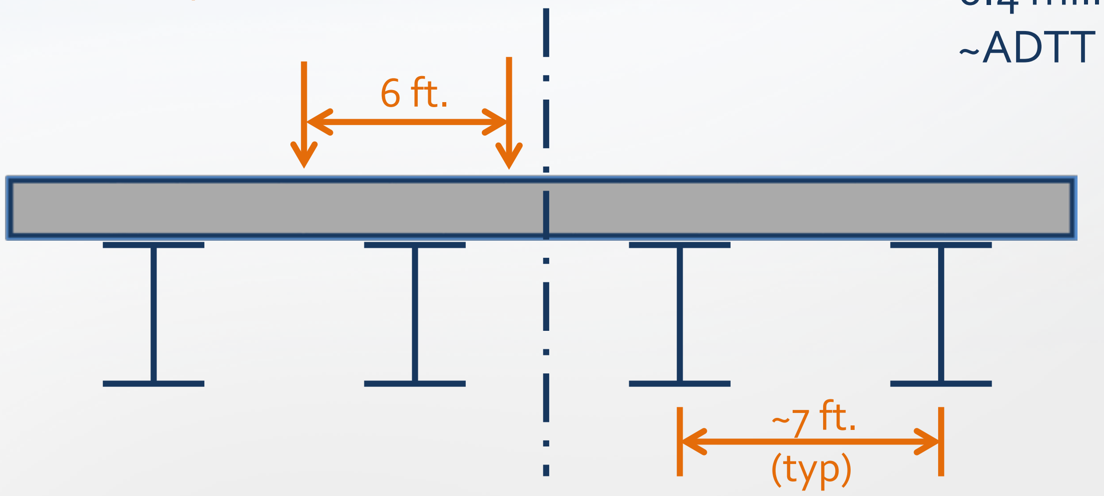






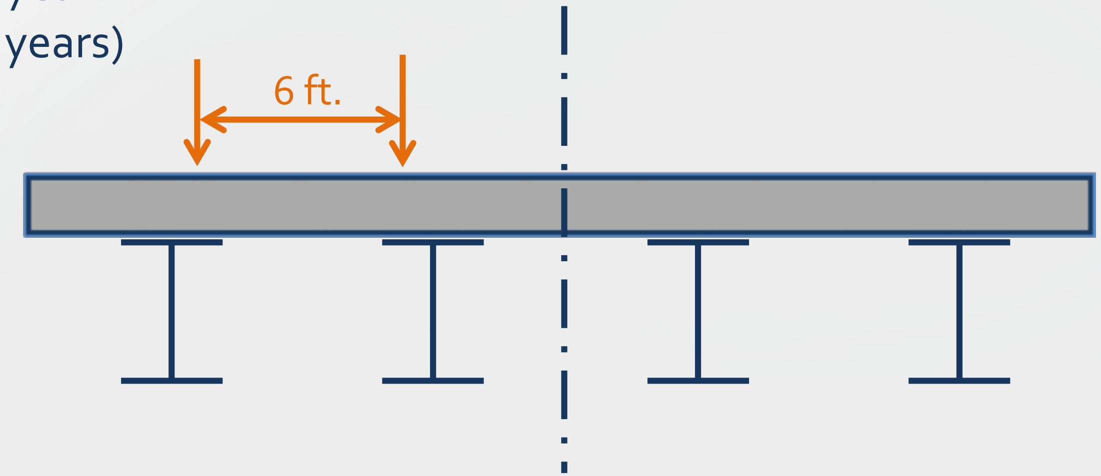
Example Loading Approaches - Live Load

Maximum, Realistic Deck Force Effects

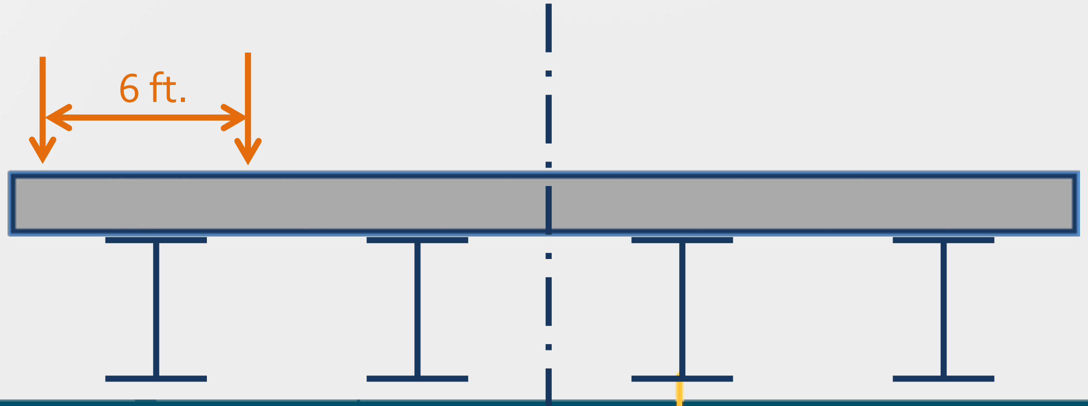


6.4 million cycles/year
~ADTT of 875 (20 years)

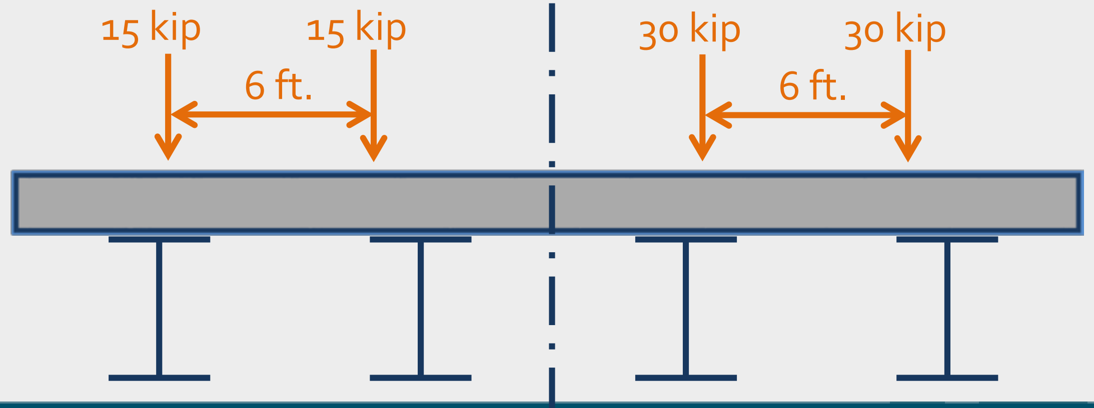
Minimum Deck Force Effects



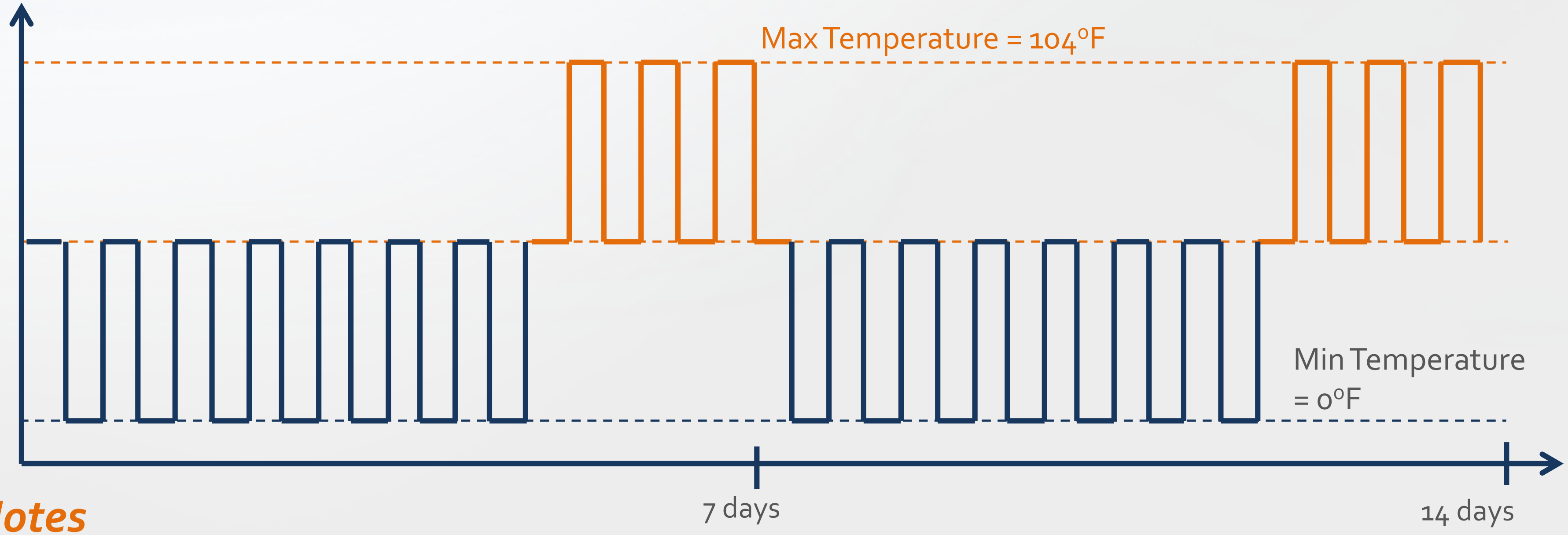
Maximum, Unrealistic Deck Force Effects



Examination of Live Load Magnitude



Example Loading Approaches – Freeze-Thaw

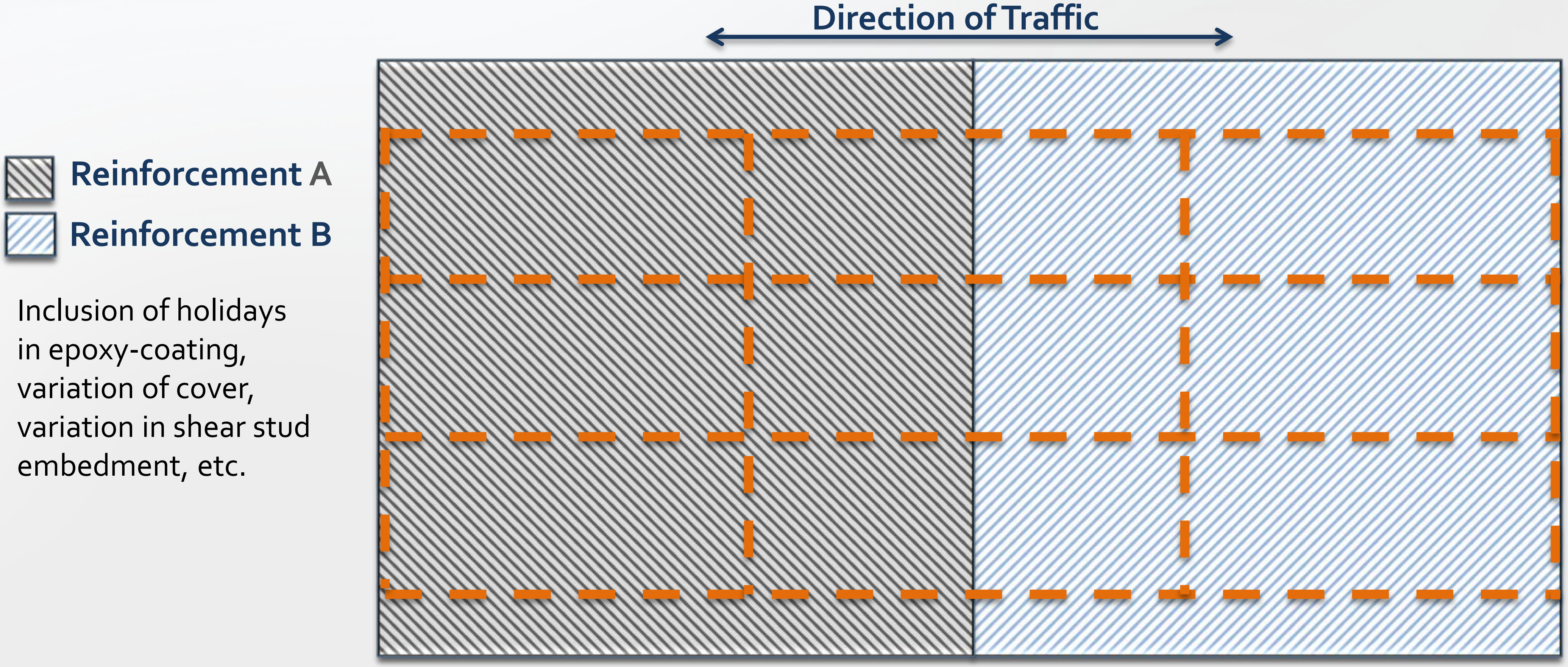


Notes

- Needs to be finalized based on simulation
- 12% brine solution applied during min temperature stages
- ~ 8 hour dwell time during freeze-thaw and hot dry cycles
- Accommodates periodic assessments during median temperature cycles
- Over 9 months this results in approximately 270 freeze-thaw cycles (Note ASTM C 666 uses a maximum of 300 freeze-thaw cycles)

Potential Testing Approach – Influence of Rebar

Phase 1 Configuration

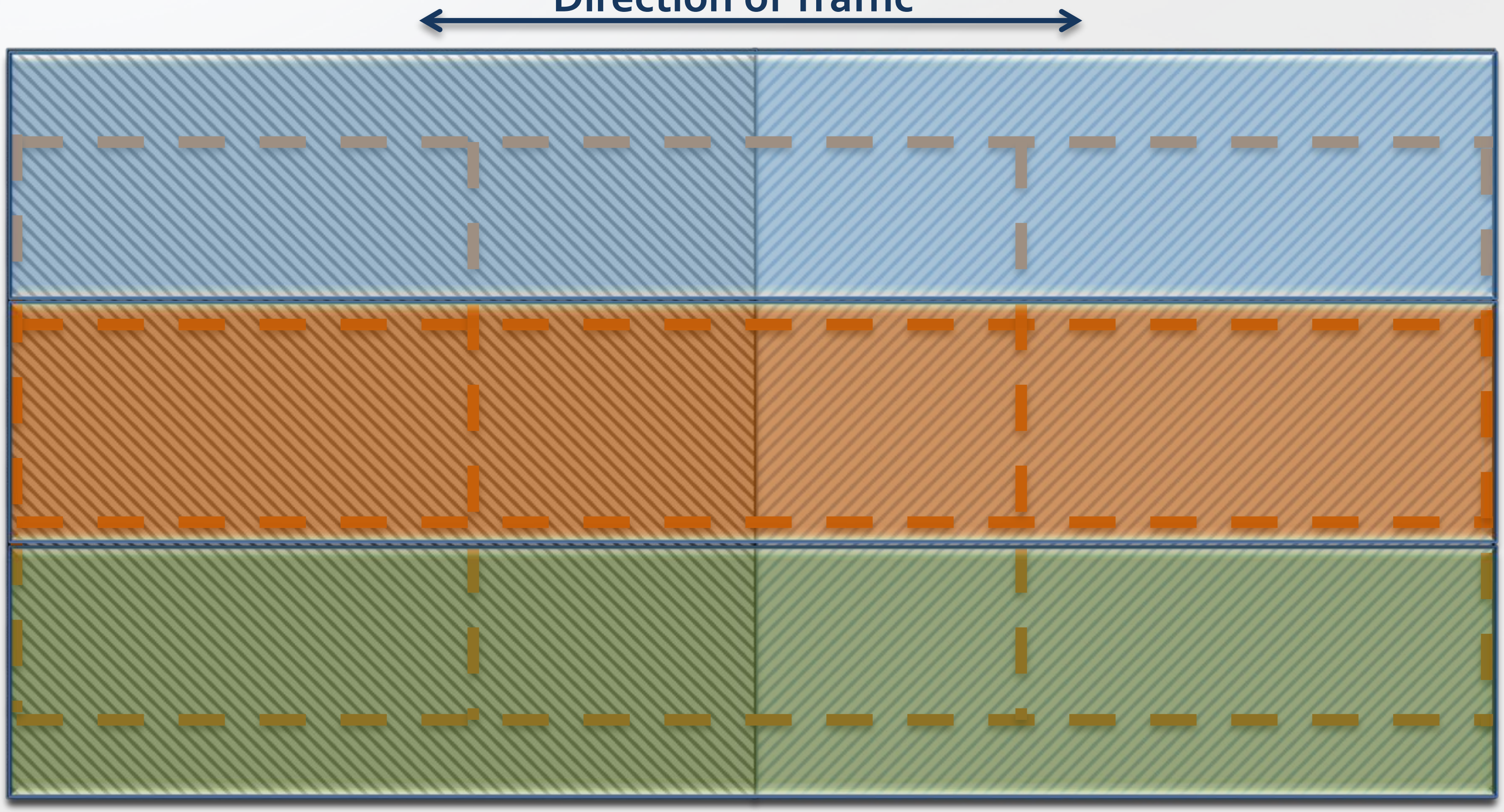


Inclusion of holidays in epoxy-coating, variation of cover, variation in shear stud embedment, etc.

Potential Testing Approach – Effectiveness of Overlays

Phase 2 Configuration

Direction of Traffic



Reinforcement A

Reinforcement B

Overlay A

Overlay B

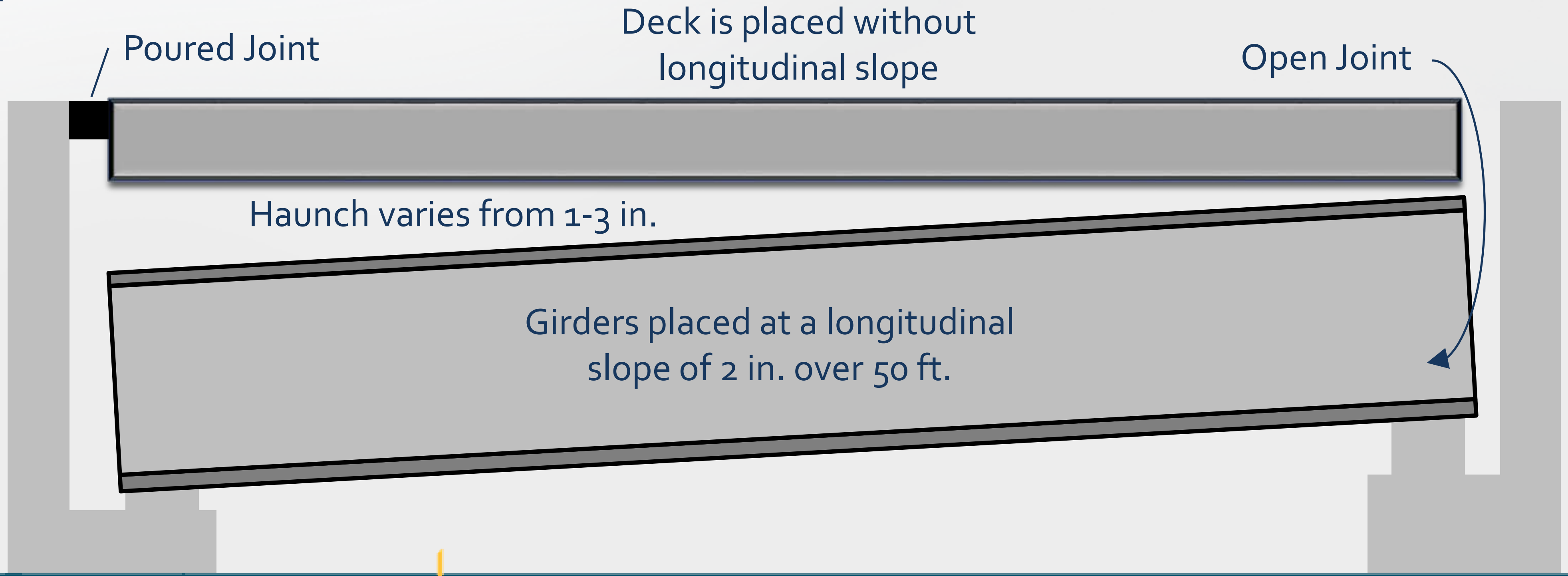
Overlay C

Note: Top of overlays must all be at the same elevation

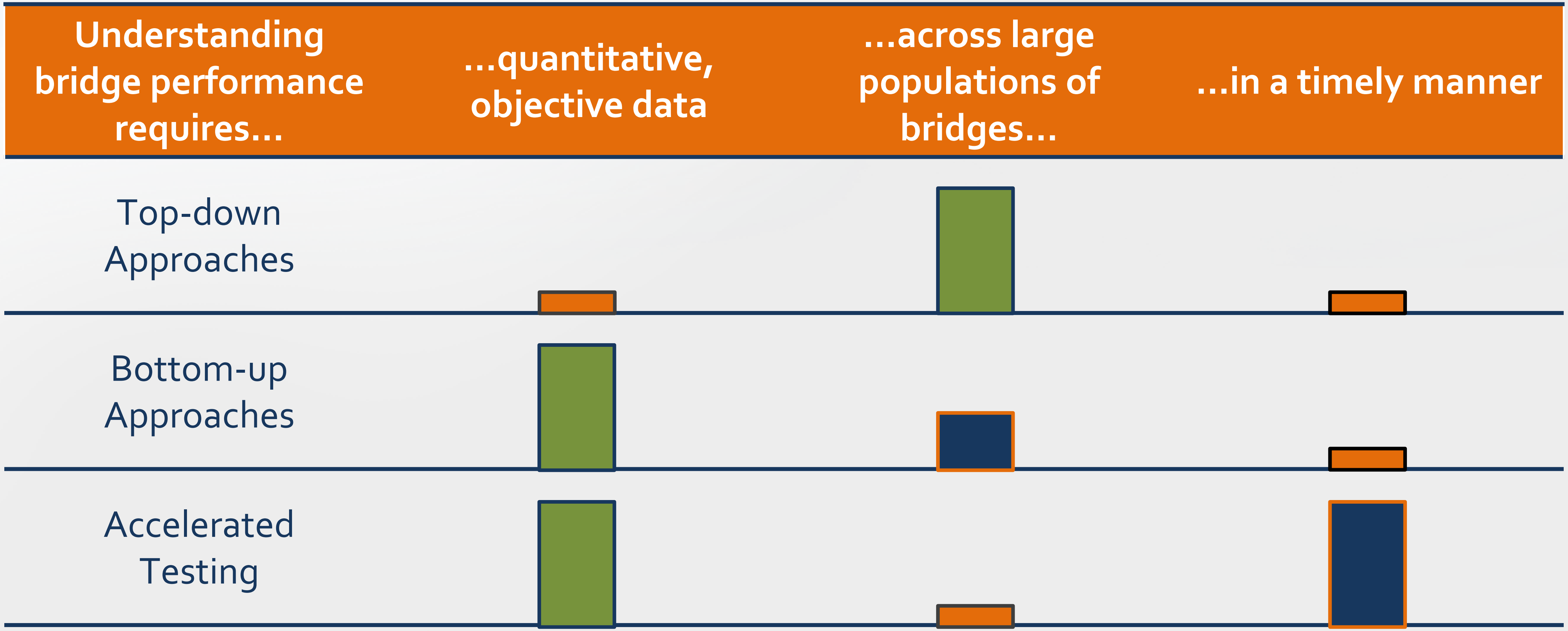
Potential Testing Approach – Performance of Steel Coatings

Coating systems:

Girder 1: Hot-dipped galvanized
Girder 2: TSM 100% Zn
Girder 3: TSM 85% Zn, 15% Al
Girder 4: Conventional Paint



Synergies Between Research Strategies



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Periodic Data Collection

(high spatial resolution, low temporal resolution)

Carried out on a base interval during Mean Temperature Cycles and based on sensor responses or thresholds

- Comprehensive, multi-modal NDE scanning (RABIT or manual)
- Modal impact testing to estimate frequencies and mode shapes (THMPER)
- NBIS Bridge Inspection
- Inspection as per LTBP Protocols

Potential Payload Projects

Long-term Performance of…

- Sensing and data acquisition
- Utilities and conduit
- Roadway condition sensors

More Fundamental Projects

- Validation of Bridge WIM
- Development and validation of approaches to integrate NDE, SHM, and visual inspection
- ***Reliability of NDE, sensing, etc.***
- Development and validation of mechanistic-based simulation modeling of deterioration
- Quantification of the reliability of model-experimental correlation approaches

Designing Experiments - Objectives and Types

Types of Objectives

- **Primary Objectives** – examine bridge performances and have significant influence over the specimen and loading protocols
- **Secondary Objectives** – examine bridge performances but have little to no influence over the specimen or loading protocols
- **Payload Objectives** – examine the performance of ancillary systems and have no influence over the specimen or loading protocols

Types of Studies

- **Longitudinal Studies** – Aim to quantitatively track performance with time to inform, calibrate, and validate deterioration models
- **Comparative Studies** – Aim to quantify relative performance between competing materials, designs, methods, etc.

Potential Focuses of Primary Objectives

Performance of Primary Components

- Longitudinal – deterioration curves for nominal bridge decks, steel coatings, joints, bearings, etc.
- Comparative – examination of different rebar coatings, steel coatings, cover depth/variability, live load levels, etc.

Effectiveness and Performance of Repair Techniques

- Longitudinal – ***deterioration curves for various overlays***, repaired decks, etc.
- Comparative – ***examination of different overlays***, different application times, different application approaches

Effectiveness of Maintenance and Preservation Activities

- Comparative – examination of bridge washing, joint cleaning, various sealants, etc.

Some Example Primary Objectives

Phase I

- Determine a base deterioration curve for ***untreated RC decks*** with both high spatial and temporal resolutions (identify the initiation and propagation rates of various deterioration mechanisms)
- Evaluate the influence of ***reinforcement type/coating*** on the performance of untreated and treated RC decks
- Establish the influence of different ***live load levels*** on the long-term performance of RC decks
- Develop base deterioration curves for various ***steel coatings, elastomeric bearings, and selected joints***

Phase II

- Establish the effectiveness of ***common overlay(s)*** at extending the service life of RC decks

Some Example Secondary Objectives

- Evaluate the ***influence shear studs*** (e.g. delamination initiators) and local stresses due to tire loads have the performance of RC decks
- Establish the ***temperature stress distributions*** and the resulting mechanical stresses that develop within composite steel multi-girder bridges
- Evaluate the ***influence of deck deterioration on structural performance*** (e.g. composite action and the transverse distribution of live load force effects)
- Determine whether there is significant ***dead load redistribution due to shake-down*** driven by thermal and live load cycles

Potential Fixed Instrumentation

(low spatial resolution, high temporal resolution)

Global

- A series of RGB cameras, including live load mounted
- A series of IR cameras

Deck

- Groups of embedded strain gages and thermistors
- Curing, dead load, temperature, live load stresses
- Redistribution of stresses due to shake-down, deterioration
- Uniform grid of chloride and corrosion sensors

Girders, Diaphragms

- Groups of 3 to 4 longitudinal strain gages (stable), thermistors, and displacement sensors: ¼-, mid-, ¾ - span
- Dead load, curing, temperature and live load stresses
- Location and migration of N.A. (dead load, temperature, live load)
- Initial and changes in transverse load distribution (dead load, temperature, live load)
- Fiber Optic WIM to capture shear forces