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PRESERVING CORRIDORS: WIM FOR AUTOMATED ENFORCEMENT IN ISHMa SYSTEMS

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AGENDA

- Team Introduction
- The Problem
- BQE Project Background
- ISHMa & the Role of Automated Enforcement
- BQE Pilot Study
- Transforming the Landscape: Policy Implications
- Conclusions and Next Steps
- Closing Remarks

TEAM INTRODUCTION

NEW YORK CITY DOT

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RUTGERS Infrastructure Monitoring and Evaluation (RIME)

Hani Nassif, Professor & Director of RIME Group and Assc. Dir. of C2SMART
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KISTLER
measure. analyze. innovate.

TRIPLE CANTILEVER DESIGN **JV**

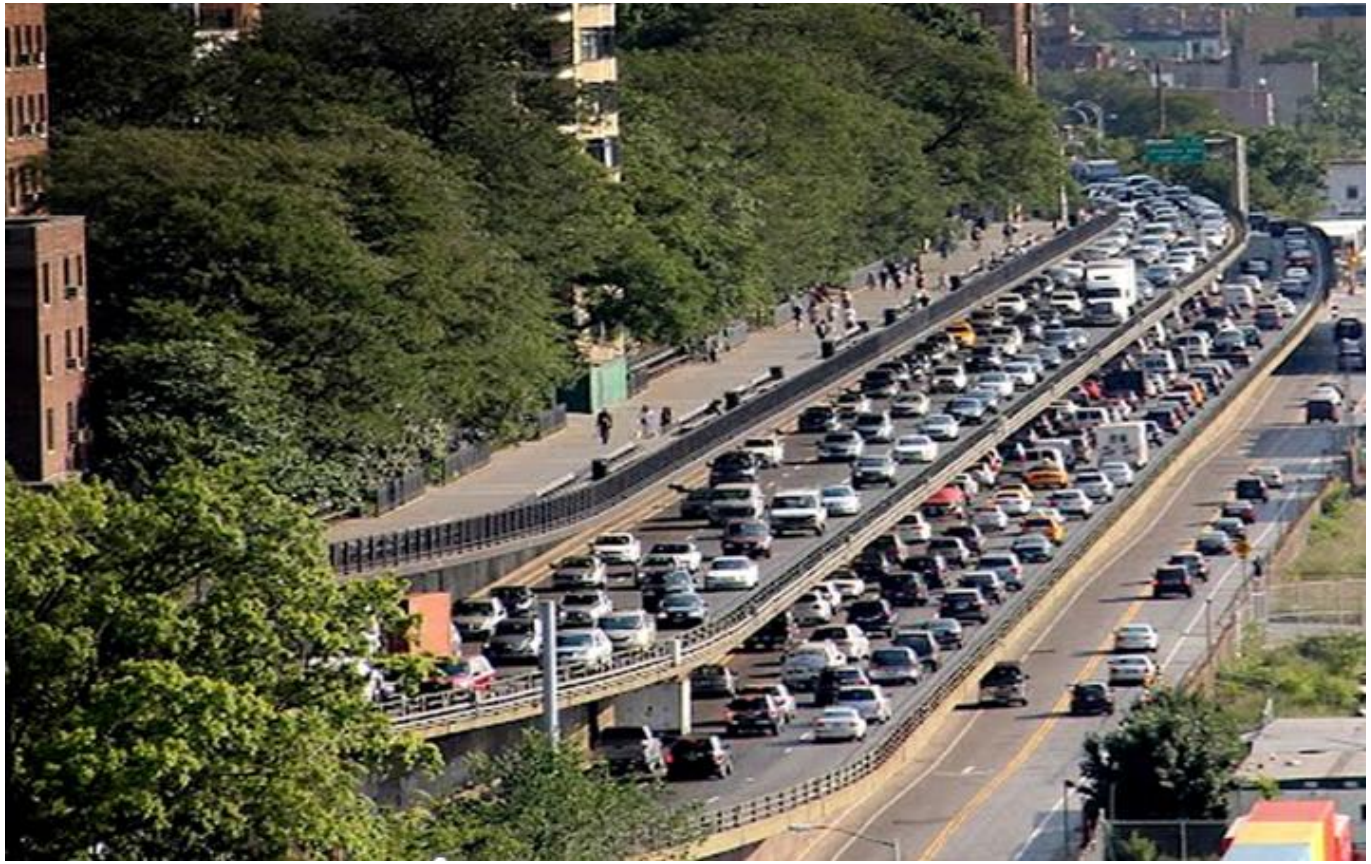
THE PROBLEM

Public agencies face an increasingly complex challenge:

Managing aging infrastructure under demands that far exceed original design expectations with **extensive (and often, uncertain) timelines** required to fund, design, and implement major rehabilitation or replacement projects.

BQE PROJECT PACKGROUND

The BQE is one of the most heavily traveled roadways in New York City, and beyond, with an average daily volume of **130,000 vehicles**, including up to 13,000 trucks:



<u>Key freight route</u>: peak volume of up to 1,100 trucks per hour (500-600 per direction) during weekday mornings.

Structural Deficiencies

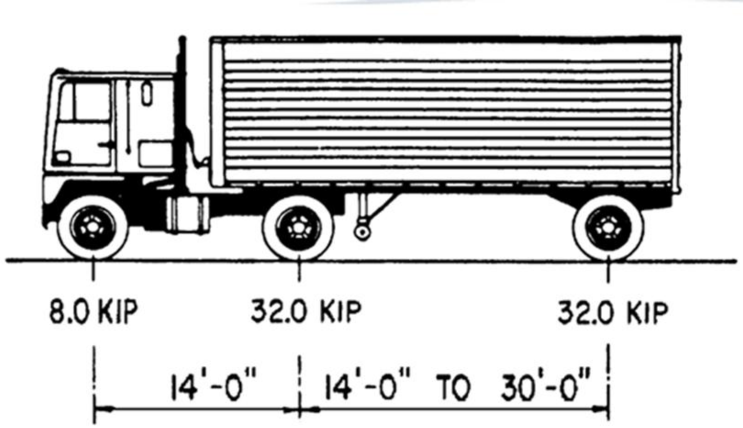
- Exposed Rebar and steel corrosion
- Concrete deterioration, spalling, and increased cracking
- Poor freeze-thaw durability
- Evidence of ASR
- 2017 Operating ratings and Materials Service Life predictions indicative of increasing structural repairs needed within the next 5 – 10 years

Roadway Deficiencies

- Nonstandard Lane widths
- Nonstandard shoulder widths
- Nonstandard vertical clearances
- Nonstandard Horizontal & Vertical curves
- Nonstandard sight distances
- Nonstandard acceleration lanes

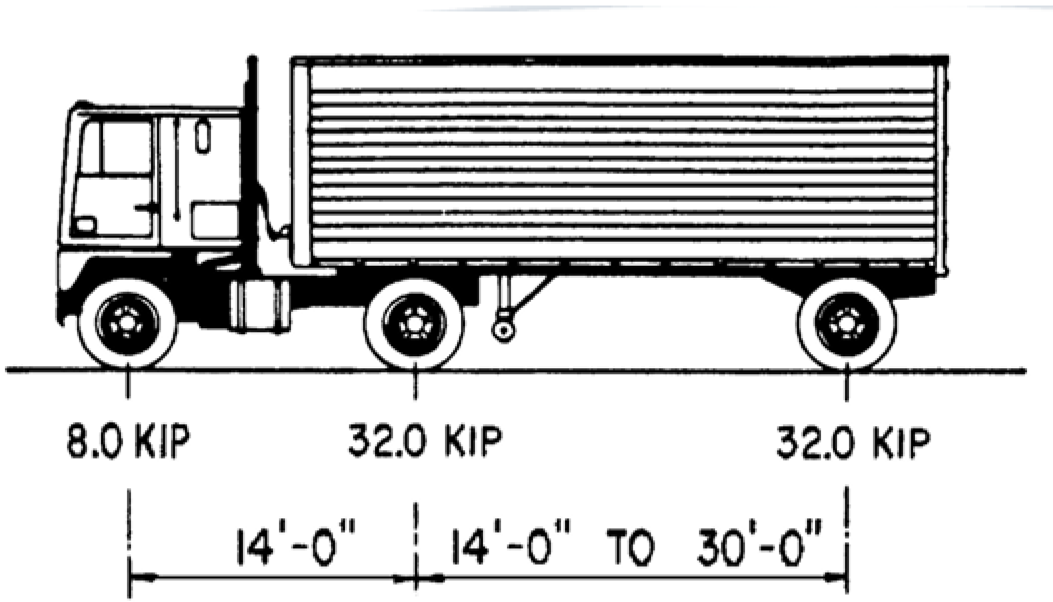
Original Engineering Parameters

- Based on A.A.S.H.O. 1941 Specifications
- Designed and constructed – 1948 - 1954



Vehicular Loading	H20-16
Pedestrian Loading	100 {SF
Soil Loading	30 PCF
All. Concrete Strength	3000 PSI
All. Steel Yield Strength	18 KSI
Pile Capacity	30 Ton Comp.

What is the Truth About Truck Loads?



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Standard AASHTO Design Truck Load

Actual Site-Specific loads

- **Queens-bound WIM sensors installed in 2019 for data collection**

2022 Data
(Queens-bound Roadway)

- Peak ADT (QB) ~ 60,000
- Peak ADTT ratio ~ 10% (6,000)
- Peak OW ratio ~ 20% ADTT (1,200)

- 80 kips < OW GVW < 115 kips

2022 Comparison of Load Factors

Staten Island-Bound

LRFD Rating	HL-93	Site-Specific	% Increase
Inventory	1.75	2.13	22%
Operating	1.35	1.68	24%

Queens-Bound

LRFD Rating	HL-93	Site-Specific	% Increase
Inventory	1.75	2.31	32%
Operating	1.35	1.83	36%

Now What?

What is the truth about....

- Load-carrying capacity?
- Steel rebar corrosion?
- Service life for a structure where corrosion has already propagated?

ISHMa & the Role of Automated Enforcement

A Holistic Approach to a Data-driven Strategy

What is ISHMa?

SHM Structural Health Monitoring	vs.	SHMa Structural Health Management
Passive Observation		Active Decision-Making
Isolated Data Collection	→	Integrated System Intelligence
Reaction "after the fact"		Pre-emptive Preservation
Asset Surveillance		Infrastructure Stewardship

"We cannot solve our problems with the same thinking we used when we created them."
— Albert Einstein

What is ISHMa?

Integrated Structural Health Management (ISHMa) is a multi-faceted, data-driven framework designed to support proactive decision-making and targeted enforcement.

At its core :

- the integration of **Structural Health Monitoring (SHM)** technologies with **Direct Enforcement Weigh-in-Motion (WIM)** systems
- Coupled with digital twin-based finite element modeling, materials assessments, and load rating analysis
- **Not just a technical advancement, but a behavioral intervention**

Components of ISHMa

Structural Health Monitoring (SHM)

- Gives continuous feedback on structure condition
- Monitors key parameters like strain, displacement, and acceleration

Weigh-in-Motion (WIM) with Automated Enforcement

- Continuously captures truck load data
- Issues real-time violations for overweight vehicles
- ***Serves both as a data source and as a behavioral deterrent***

Components of ISHMa

Digital Twin Finite Element Analysis (FEA) Model

- Simulates dynamic and static response
- Incorporates SHM-derived stiffness parameters

Materials Assessment via Non-Destructive Testing (NDT)

- Provides insights into structural deterioration, including rebar corrosion
- Informs repair prioritization

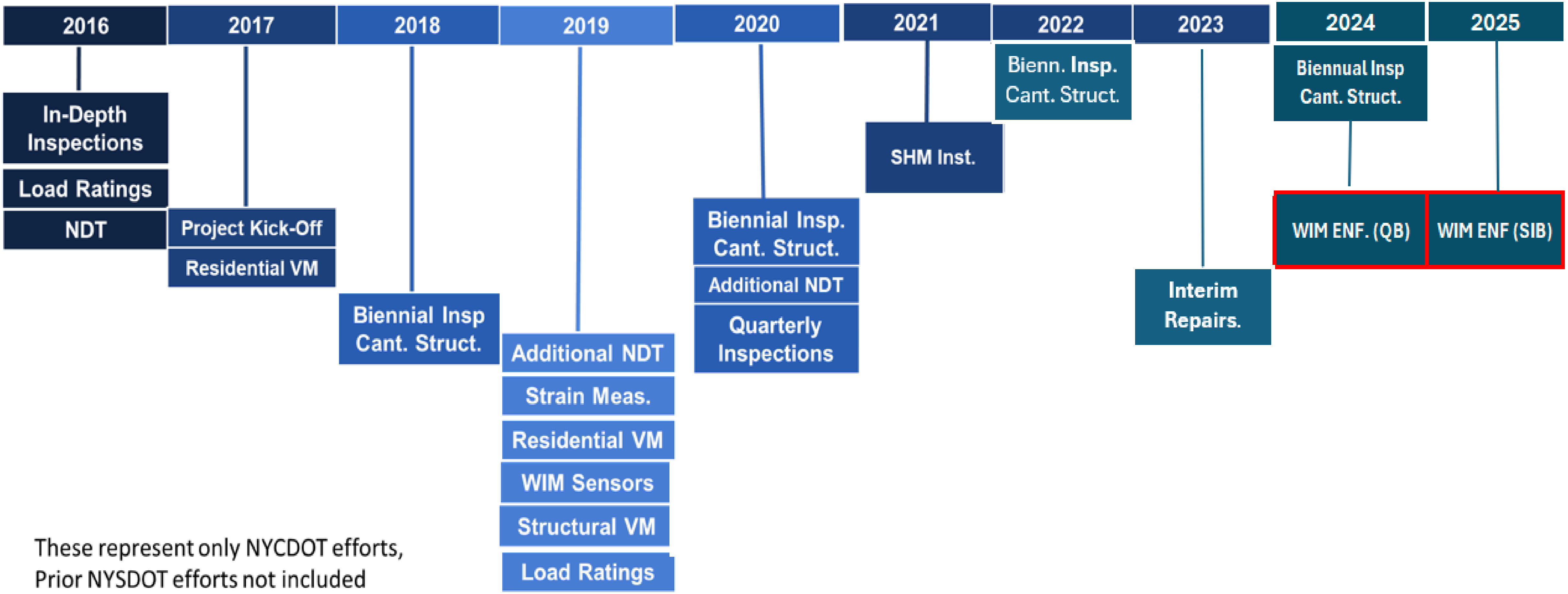
Load Rating Analysis

- Quantifies load-carrying capacity
- incorporates both live load data and materials degradation to update service life projections and support maintenance planning.

BQE Pilot Study

An Evolution:
A Targeted Approach to Service Life Extension

BQE Health Monitoring efforts have been on-going since the Project Kick-Off in the Fall of 2017



These represent only NYCDOT efforts,
Prior NYSDOT efforts not included

Structural Health Monitoring (SHM)

SHM – Sensor Types and Placement

- **Integrates targeted instrumentation with regular walk-through inspections and data evaluation**

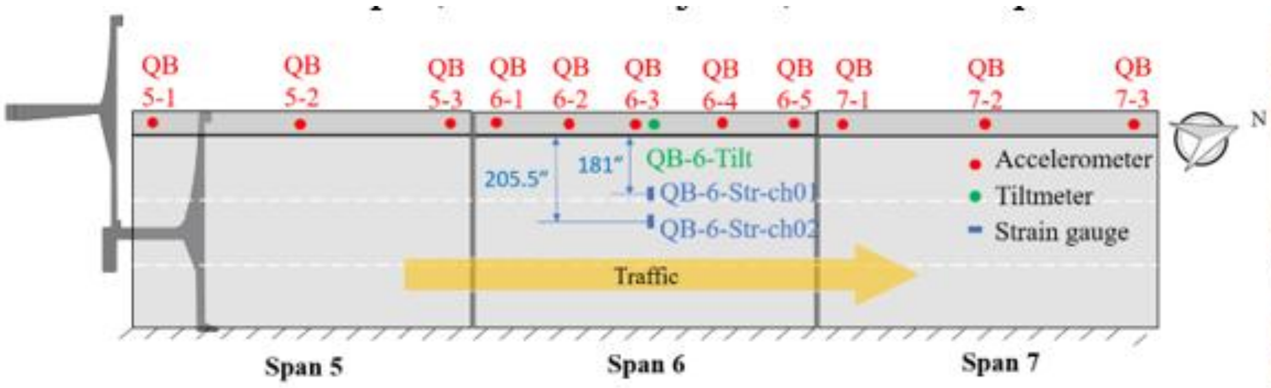
- **Goal is twofold:**
  - to monitor structural behavior under real-time loading conditions
  - to identify both urgent and interim repair needs in a manner that is responsive to observed performance

- System comprises two primary types of wireless instrumentation—**accelerometers and strain transducers**—strategically installed to track critical performance indicators across spans of varying condition

SHM – Sensor Types and Placement

- **Installed on two critical spans of the SIB/QB cantilever decks**
    - One span which materials testing had classified as being in relatively good structural condition.
    - One span which materials testing had classified as being in relatively poor condition due to advanced materials degradation.

- **Dual-span approach allows for comparative analysis and performance benchmark-ng between structurally divergent sections of the BQE.**

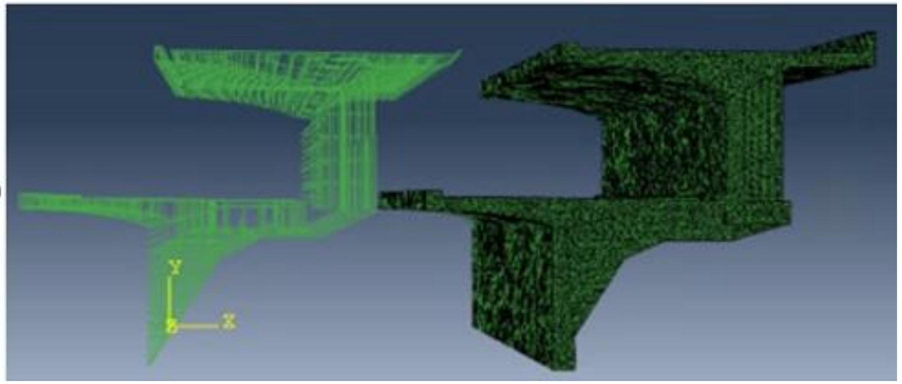


Finite Element Modeling & the Digital Twin

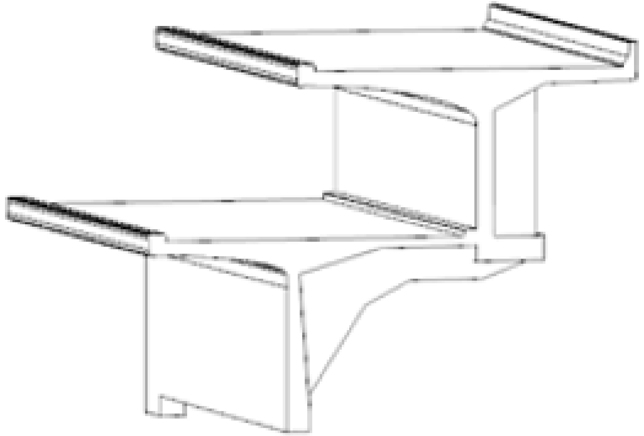
Finite Element Modeling & the Digital Twin

- **Developed using Abaqus CAE**

- **Calibrated against structural monitoring data, materials testing results, and field runs with known truck weights**



  - **Focused on matching the natural frequencies derived** from field-measured acceleration data to those predicted by the FEA model
  - **Elastic modulus** identified as the most effective parameter for reflecting real-time degradation and was therefore prioritized in the model calibration process



Finite Element Modeling & the Digital Twin

- **Once calibrated, the digital twin becomes a powerful diagnostic and predictive tool within the ISHMa framework**.

- **By inputting real-time load data from the WIM system and structural response data from SHM**, the model can simulate:
  - Structural demands under both legal and overweight vehicle scenarios
  - Localized effects of material degradation
  - Long-term fatigue accumulation
  - Potential failure mechanisms

WIM & Automated Enforcement

WIM & Automated Enforcement

- Enables the measurement of axle loads, gross vehicle weight (GVW), axle spacing, and vehicle speed as vehicles travel at or near highway speeds
- **The first in the United States designed and certified specifically for direct enforcement of overweight violations on a public roadway.**
- Installed on the Queens-bound and SIB-bound lanes and consists of **eight Kistler quartz sensors and two inductive loops per lane, configured in a zigzag pattern**
- Well-suited for low-speed, varying speeds of urban traffic
  - Provides two independent weight readings along with time stamps per vehicle.
  - Accounts for accuracy need in varying conditions

WIM & Automated Enforcement

- Calibration performed in accordance with the proposed amendment to NIST Hand-book 44, which outlines procedures for certification of equipment used legal weight measurements.
  - Diverse fleet of six calibration trucks selected, with known wheel and gross weights verified using certified scales for reference.
  - Each vehicle passed over the sensors multiple times at varying speeds to meet statistical requirements
- **Following successful calibration, the New York State Department of Agriculture and Markets certified the site, authorizing NYCDOT to issue violations based on WIM-derived measurements.**

WIM & Automated Enforcement

- **What elevates this WIM system beyond traditional monitoring tools?**

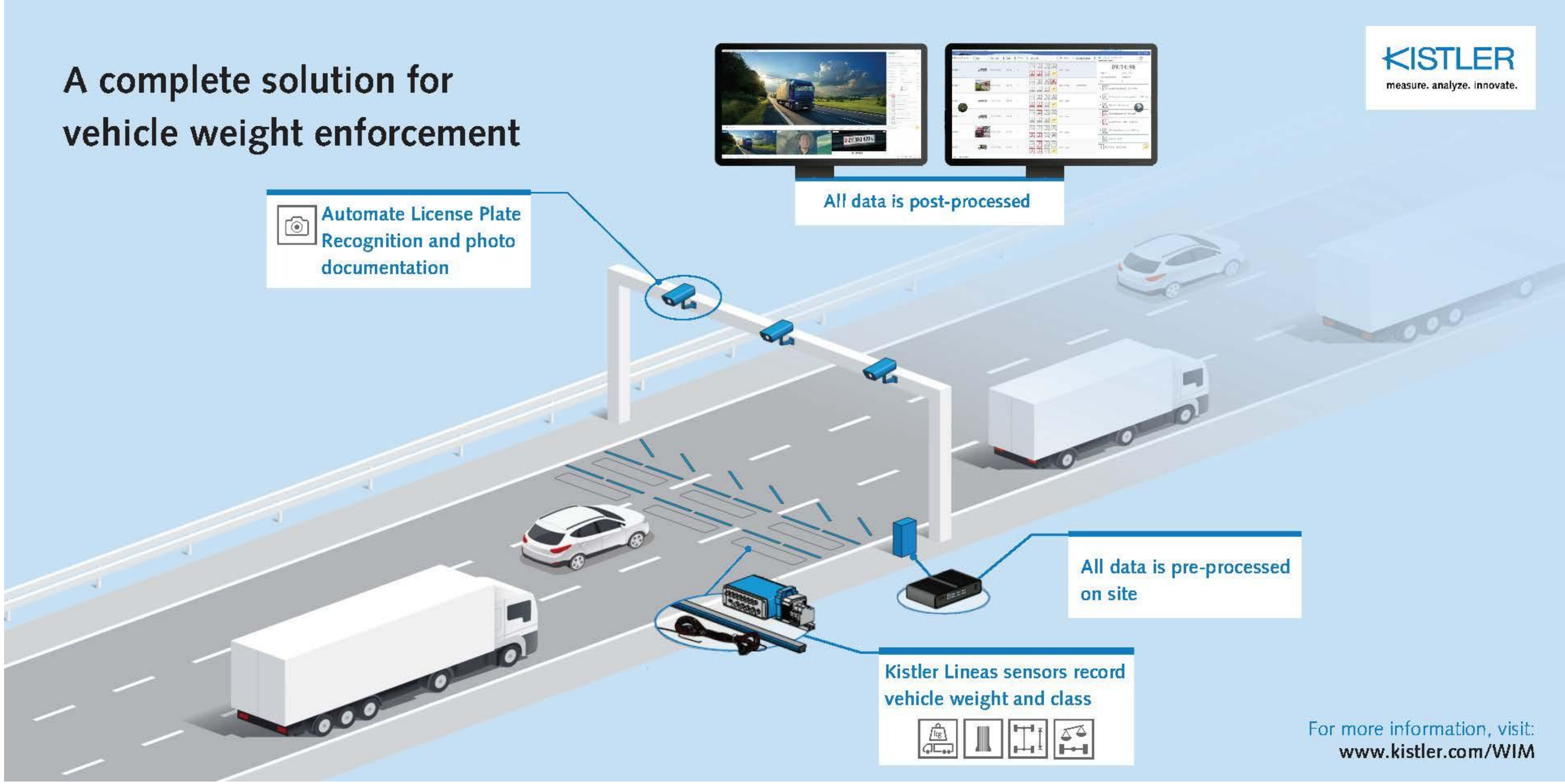
  its integration with automated enforcement workflows.

- As vehicles pass over the sensors, the WIM system captures axle loads, GVW, speed, and axle configuration in real time, identified violation.

- Simultaneously, high-resolution cameras capture license plate images and vehicle characteristics, transmitted to trained NYCDOT personnel, who verify that a violation has occurred.

WIM & Automated Enforcement: Sample System Configuration

Follows the legislative requirements for evidentiary package & code requirements



WIM & Automated Enforcement: Violation Notice Requirements

Gross Vehicle Weight Violations

- Date and time of violation
- License plate photograph
- GW Measured per sensor set
- Allowable maximum Weight per bridge formula
- Link to website for view record online
- NOL issued to Owner / Responsible Party (Rental)

QB BQE enforcement: November 2023
SIB BQE enforcement: June 2025

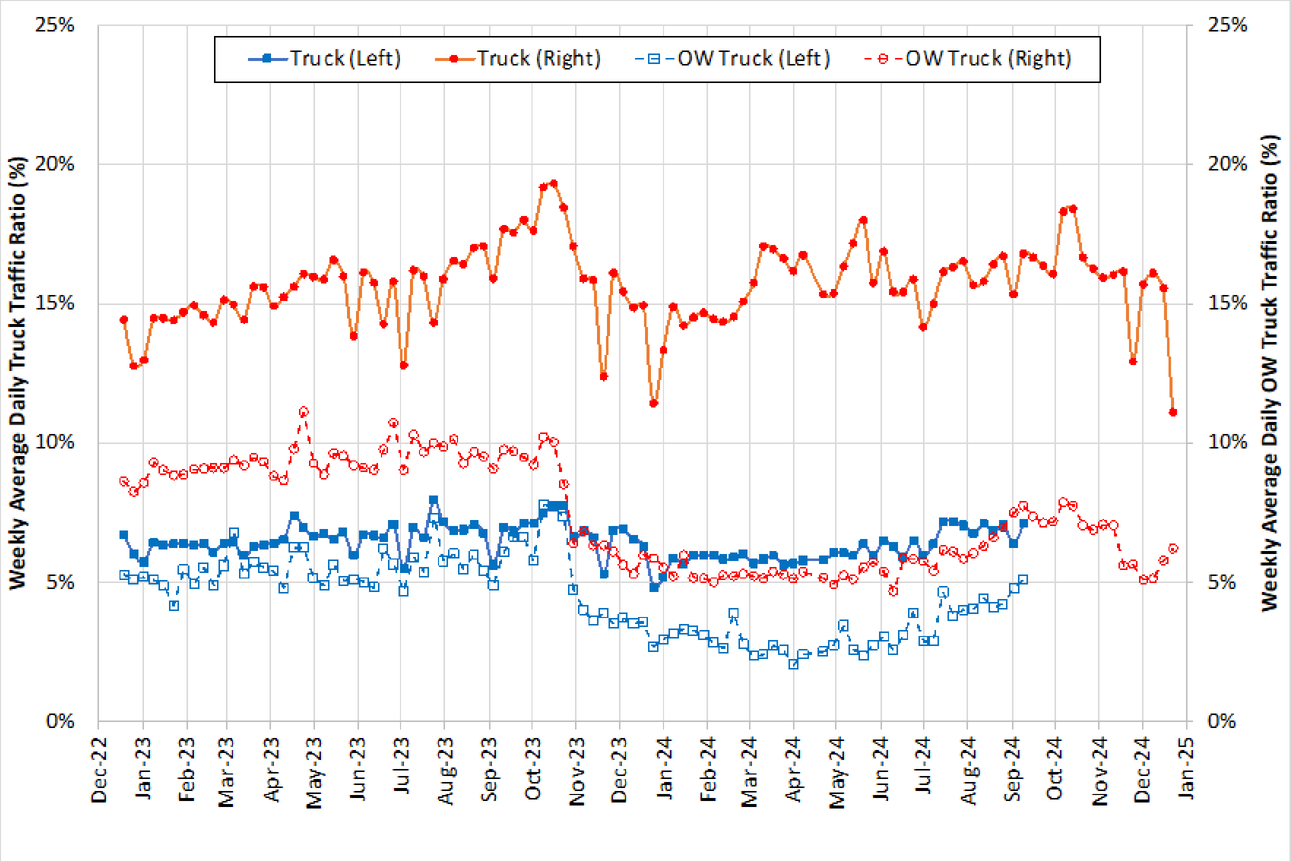
Axle Weight Violations

- Date and time of violation
- License plate photograph
- Each Axle Weight Measured per sensor set
- Allowable maximum for the axle in violation per bridge formula
- Additional tabulation of axle spacing and weights for identification of axle in question, e.g., tandem
- Link to website for view record online
- NOL issued to Owner / Responsible Party (Rental)

WIM & Automated Enforcement: Traffic Trends

- Prior to October 2023, OW truck ratios for Queens-bound traffic reached approximately 9–10% in the right lane and 5–6% in the left lane.

- **Following the launch of automated enforcement in November 2023, these figures dropped by roughly 60%.**



Materials Assessment

Materials Assessment

- Two main goals:
  - **supports the identification of the "end of materials service life"** – the time at which deterioration has progressed to the extent that mitigation is required, regardless of remaining structural capacity
  - **provides quantified estimates of corrosion loss and rates** - directly fed into structural models to calculate the remaining service life based on structural capacity thresholds.

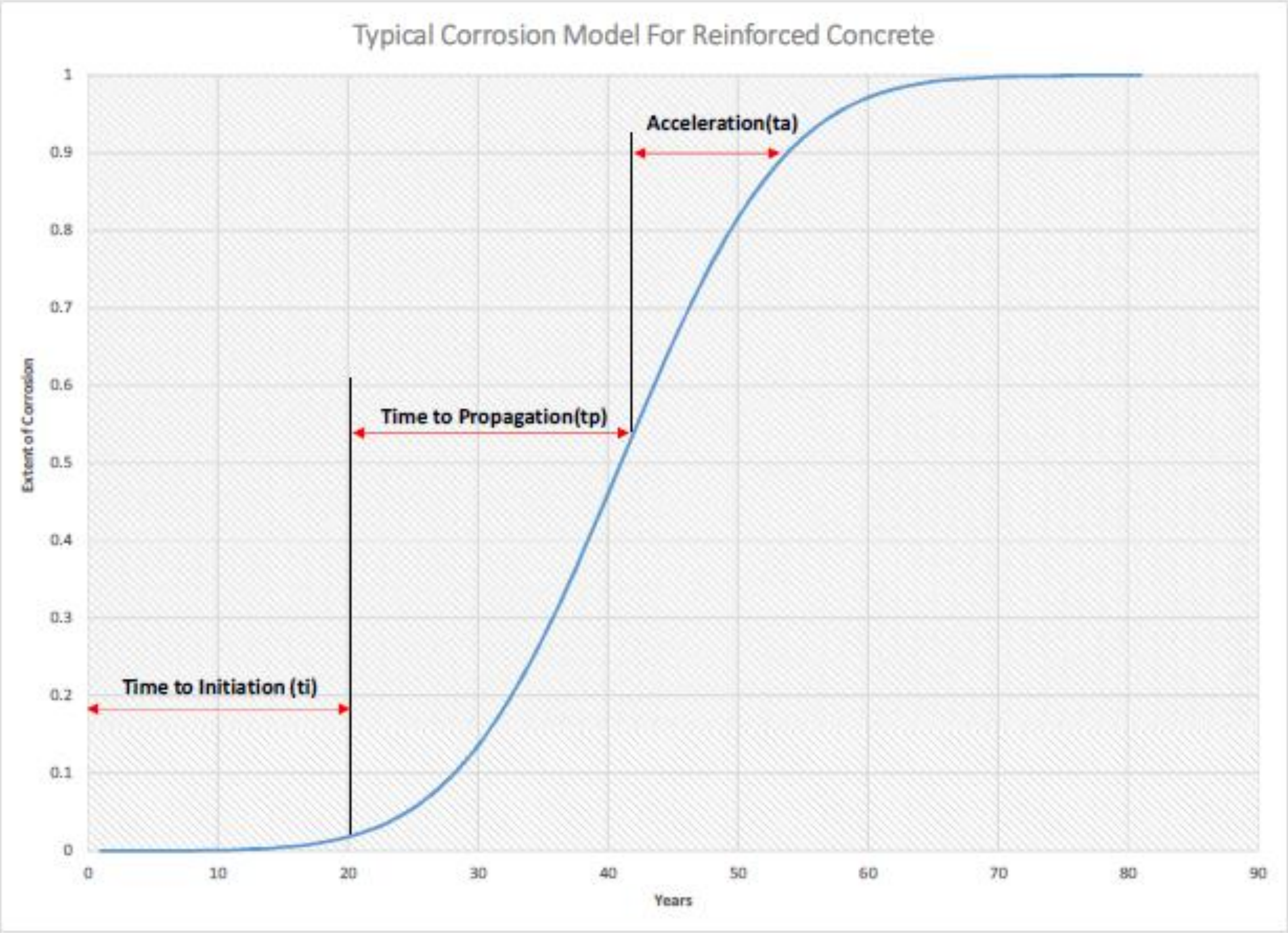
- **<u>Exposes the considerable difficulty public agencies face in defining deterioration limits, particularly for aging infrastructure</u>.**
  - must consider technical indicators, as well as operational context, performance history, and the interplay with structural demands.

Materials Assessment: Corrosion Rate Estimation

- **Corrosion rate estimation remains one of the most underdeveloped and often "black box" components in life-cycle modeling literature—particularly in the post-initiation and propagation phases.**

- For the BQE cantilever decks, a five-point scoring system developed around four distinct parameters was used:
  - MASPAR propagation velocity (rate at which corrosion advances)
  - Air Void Analysis (volume of permeable voids enabling ionic movement)
  - Chloride content (at reinforcement depth)
  - Half-cell potential (electrochemical indication of corrosion activity)

Materials Assessment: Corrosion Rate Estimation



Materials Assessment: "End of Materials Service Life"

- NYCDOT adopted a multi-limit approach to defining residual service life for the BQE R/C cantilever structures:

  - **SLS 1: Initiation phase**, defined as the point at which the structure's ability to resist ingress of chloride or carbon dioxide is compromised, reducing the reliability index below 1.3.

  - **SLS 2: Propagation phase**, characterized by section loss due to active corrosion.

  - **SLS 3: Acceleration phase**, where section loss exceeds 25%, corrosion activity intensifies, and the material integrity becomes increasingly compromised.

Materials Assessment: “End of Materials Service Life

So, what constitutes the “end of materials service life”?

- SLS 3 was selected as the upper-bound threshold for end-of-materials service life **with the recognition that this must always be evaluated in conjunction with other performance indicators.**

- 25% section loss (SLS 3) is not treated as a hard failure point. **Instead, it serves as a reference metric for evaluating the urgency of intervention, when combined with data from SHM, inspections, and structural models.**

Materials Assessment: Key Conclusions

- Consisted of a series of investigations from 2016 to 2024
- Involved hundreds of petrographic core samples, strategically selected probe locations, and correlation with theoretical models.

- **Primary conclusions include:**
  - Wide variability in corrosion states across spans
  - Evidence of chloride migration to reinforcement depth exceeding industry thresholds
  - Corrosion propagation initiated as early as the 1970s in certain segments.
  - Residual service life estimates varied span-by-span.
  - Based on available data, 27 of the 114 spans of the SIB & QB roadway cantilever decks controlled by materials service life

Load Rating Evaluation

Load Rating Evaluation

- The first stage in the load rating analysis was to establish site-specific live loads using actual truck traffic captured by the WIM system.

- This approach followed a four-step methodology:
  - **Representative Truck Identification** - Representative truck configurations extracted from WIM data
  - **Load Effect Calculation-** Representative trucks input into the calibrated digital twin (FEA model) to simulate the load effects
  - **Return Period Extrapolation**-Statistical analysis performed to extrapolate maximum load effects corresponding to various return periods (e.g., 5, 10, 50, and 75 years)
  - **Normalization to HL-93 Design Truck**-Load effects normalized to the AASHTO HL-93 design load,

Load Rating Evaluation

- **Structural capacity over time** modeled using corrosion loss projections derived from the materials assessment.

- capacity estimates paired with the structural demands generated in the digital twin to evaluate remaining service life under two key thresholds:
  - **Inventory Rating**: Higher live load factors (Live Load Factor = 1.75), representing in-definite usage under standard conditions.
  - **Operating Rating**: Lower live load factors (Live Load Factor = 1.35), representing acceptable usage for a defined short-term period (typically 5 years).

Load Rating Evaluation

- Two distinct WIM datasets were analyzed to evaluate the preliminary effect of the ISHMa system's enforcement component:
  - **Pre-Enforcement Period: December 20, 2022 – September 20, 2023**
  - **Post-Enforcement Period: January 1, 2024 – July 29, 2024**

- **Site-specific live load factors calculated for each period:**

Rating Type	Pre-Enforcement LL Factor	Post-Enforcement LL Factor
Inventory	2.20	**1.75**
Operating	1.60	**1.27**

- Note: Post-enforcement time period documented is roughly 7 months. Longer time periods are needed to validate preliminary results.

TRANSFORMING THE LANDSCAPE: POLICY IMPLICATIONS & LEGAL ENFORCEMENT

Lessons Learned and Lasting Impacts

From Legislation to Implementation

- NYCDOT's journey has extended far beyond the physical deployment of sensors.
- It has included:
  - **Spearheading legislation**
  - **Proposing regulatory updates**
  - **Building interagency and stakeholder alignment.**
    - Commercial Vehicle Safety Alliance (CVSA),
    - National Institute of Standards and Technology (NIST)
    - ASTM International
    - Freight and trucking industries,
    - Elected officials
    - Other transportation agencies.

From Legislation to Implementation

- Under the original authorizing legislation, NYCDOT permitted to install up to sixteen WIM sensors along BQE Central, covering the segment from Atlantic Avenue to Sands Street.
- **Violations issued only when trucks exceed:**
    - **gross vehicle weight by 10% or more, or**
    - **axle weight by 20% or more**
- **Each violation carries a $650 fine**; trucks exceeding both limits may be cited for both.
- WIM systems must be calibrated and recertified every 6 months by the NYS Department of Agriculture and Markets.

Statewide Ripple Effects

In 2025, New York enacted Senate Bill S6383, expanding the authority to use WIM-based enforcement to other major infrastructure owners, including:

- Triborough Bridge and Tunnel Authority
- New York State Thruway Authority
- New York State Bridge Authority
- Port Authority of New York and New Jersey

Signaling a broader policy shift toward integrating behavioral enforcement with infrastructure preservation.

Impacts

- **Roughly 60% reduction in overweight trucks during the first year of operation**
  - Drop in overweight vehicle share from 5.1% (2023) to 2.2% (2024)
  - Pre-enforcement monthly average: 7,920 overweight trucks
  - Post-enforcement monthly average: 3,354 overweight trucks

- **Reductions achieved without a decrease in overall truck volume**
  - **enforcement, not reduced demand, drove compliance.**

- **Between November 13, 2023, and October 28, 2024, 2,306 violations were issued, with 1,576 paid in some amount and 1,515 paid in full, yielding over $1 million in revenue.**

- **Majority of violations upheld in court or settled without dispute**

CONCLUSIONS & NEXT STEPS

Conclusions

- Site-specific live load factors, derived from BQE WIM data, revealed actual traffic loads well above standard HL-93 design assumptions
- **Automated WIM enforcement reduced the presence of overweight vehicles by 60%**
- Load ratings using updated post-enforcement data showed improved margins, with site-specific load factors decreasing from pre-enforcement values

These findings affirm that ISHMa is an essential evolution in how we manage aging infrastructure in complex urban environments.

Next Steps

To build on the success of this initiative, the following areas of work are recommended:

- Formalize National Standards for Automated WIM Enforcement
  - Support the final approval of draft updates to NIST Handbook 44 and ASTM standards for WIM used in legal enforcement.
- Engage with national regulatory bodies to ensure that these updates reflect the practical lessons learned on the BQE.
- Advance Reliability-Based Load Rating Models
  - Current AASHTO-based thresholds assume a uniform risk profile that may not align with the actual complexity or criticality of a structure.

Next Steps

- **Explore how risk-based assessments could refine operational decision-making—particularly in urban corridors where failure consequences are high.**

- **Institutionalize ISHMa in Urban Infrastructure Management**
    - Encourage state DOTs and large municipalities to pilot ISHMa frameworks on critical corridors.
    - Invest in workforce development, data infrastructure, and regulatory pathways that support sustained implementation.

Closing Remarks

- **In corridors as vital as the BQE—where infrastructure performance is directly tied to regional mobility and economic function—continued reliance solely on theoretical design loads amounts to risk blindness**

- This study reinforces a truth long avoided in infrastructure circles:
  - Weight limit enforcement is not optional—it is structural preservation.
  - ***For decades, public agencies have accepted systemic overloading as inevitable. ISHMa challenges this narrative, offering not only visibility into the violation of overweight restrictions, but also tools to stop it.***

QUESTIONS?