Predicting Congestion Onset at the Chesapeake Bay Bridge:

A Machine Learning Approach with Weighted Sampling for Proactive Work Zone and Facility Management

Maryland Transportation Authority Case Study

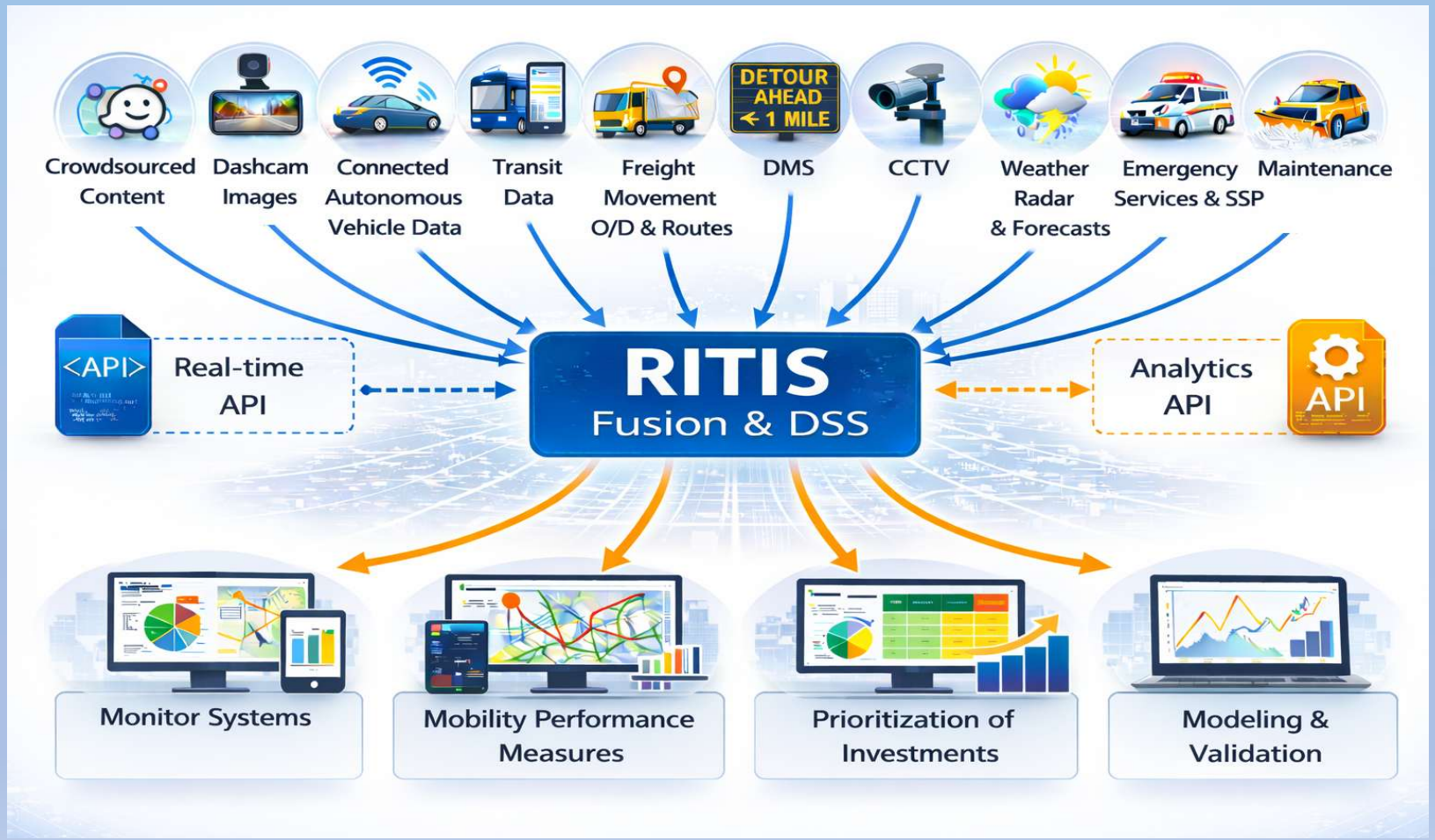
Agenda

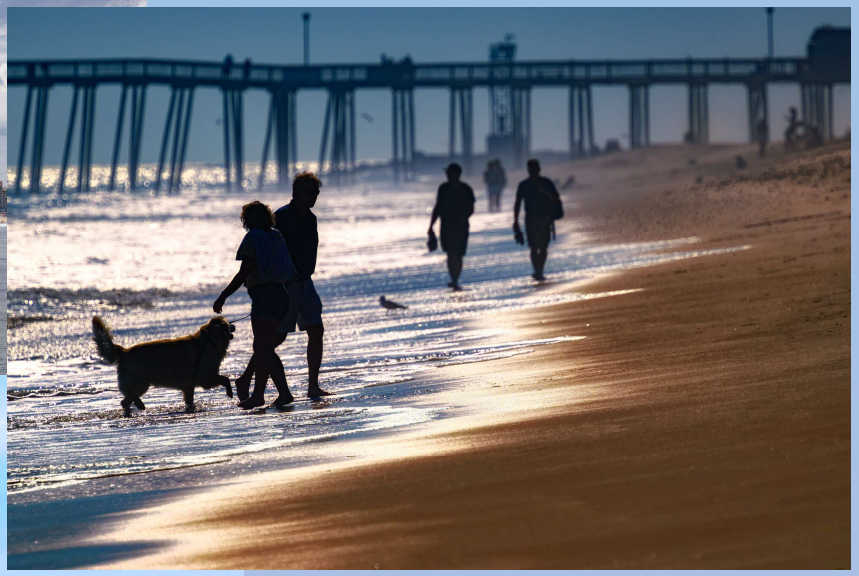
- Background
  - CATT Lab
  - Chesapeake Bay Bridge
  - Goals and Objectives
- Web Application Overview
  - Data and System Architecture
  - Sensor locations
  - Operational view
  - Queue identification and prediction logic
  - Queue prediction view

CATT Lab

- Center for Advanced Transportation Technology Laboratory
- The CATT Lab operates the world's largest transportation data archive and analytics platform
- Recognized leader in applied big-data analytics for mobility applications (operations, planning & research)

Regional Integrated Transportation Information System






OC FISHING PIER
ICE
GIFTS
ROD RENTAL
BAIT AND TACKLE


EXIT 32
Oceanic Drive
Sandy Point State Park
1/2 MILE
LAST EXIT BEFORE TOLL
EXIT 31
Whitehall Road
15 MPH
LEFT LANE CLOSED
Atlas
go new places.
ROGUE
SV AWD
CR-V
AWD
EBX-7840

Project Background

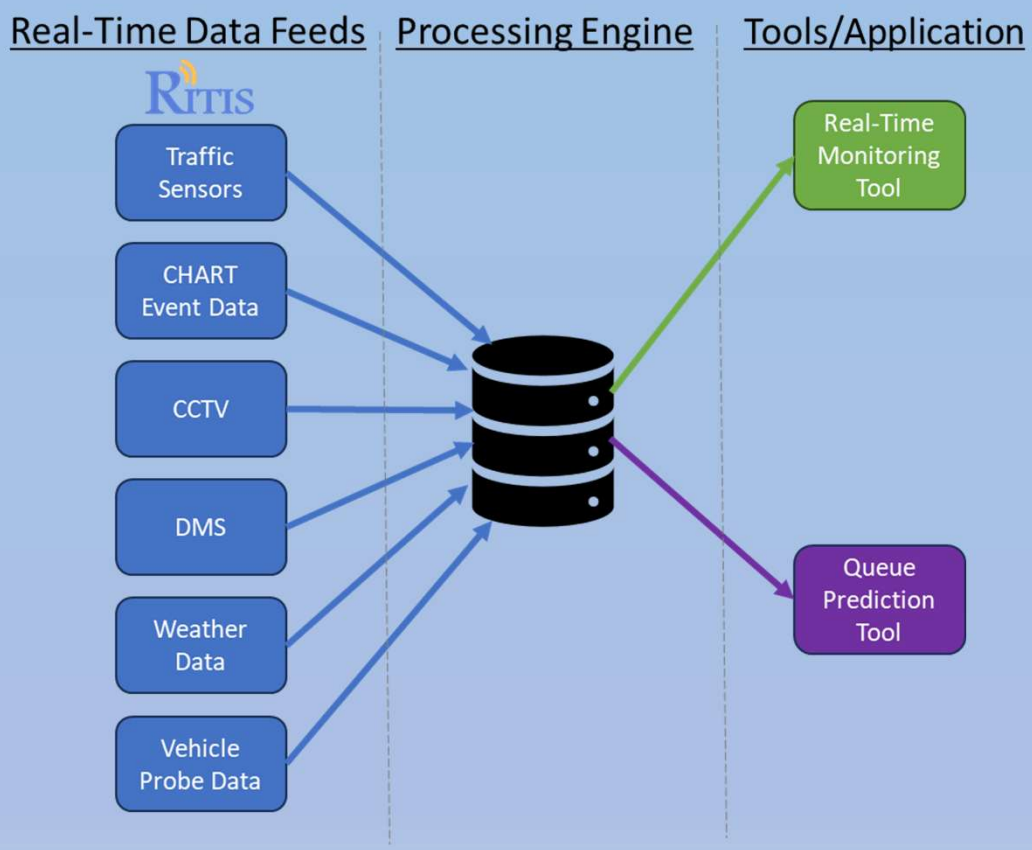
- **Two spans**
  - Northern span (3 lanes) WB
  - Southern span (2 lanes) EB
- Any lane can be closed for maintenance or roadwork
- Center lanes may be converted to contraflow
- Flexibility improves flow but increases operational complexity
- Total reconfiguration can take up to 45 minutes
  - (15 mins decision / 30 mins reconfiguration)
- Automated lane closure system can reduce switch time to 15 mins
- Peak seasons and major rehabilitation projects can lead to long queues

Goals and Objectives

- To optimize capacity allocation by traffic predicting and proactively managing congestion on lanes

Legacy Method	Modern Approach	Outcomes
➢ Manual ad-hoc decision process ➢ Data and performance measures spread across multiple platforms ➢ Future conditions predictions based on operator experience and intuitions	➢ Centralized, user-friendly interface ➢ Automated , data-driven real-time performance analysis ➢ Predict future conditions ➢ Supports proactive safety and mobility interventions	➢ **Efficiency:** Faster, clearer lane management decisions ➢ **Congestion Reduction:** Early queue detection and mitigation ➢ **Safety:** Alerts for crashes, slowdowns, and weather effects ➢ **Coordination:** Unified platform for operations, maintenance, planning ➢ **Transparency:** Visualizations for performance reporting and documentation ➢ **A smarter, safer, and more predictable bridge operation environment**

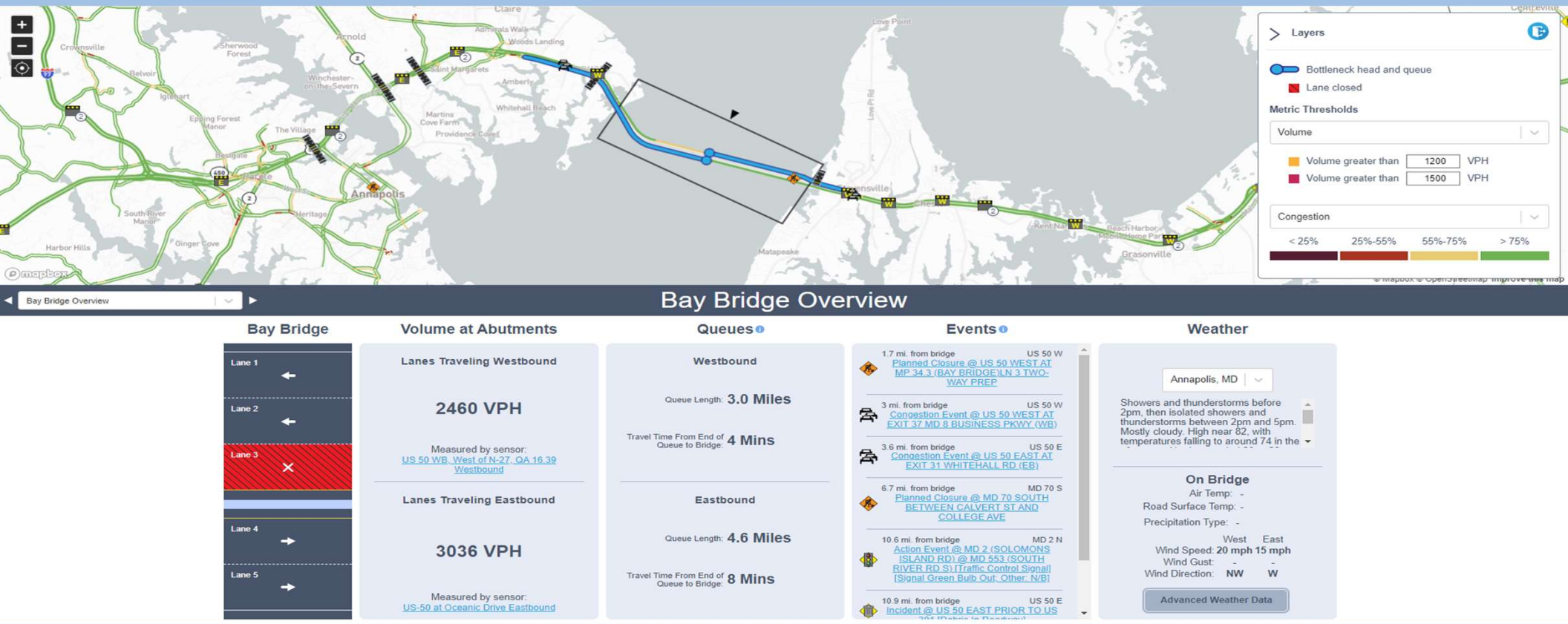
Current System Architecture Overview



Sensor Deployment and Data Collection

- A layout for deploying traffic sensors was developed to allow for more accurate measurements of the queue length.
- 24 Wavetronix sensors: speed & volume
- 15 Blue Toad sensors: travel times between points
- Sensors every 0.25 mile over a 2-mile queue zone
- Additional sensors on approaching arterials
- Enables early detection of queue buildup and congestion propagation

Real-time Monitoring



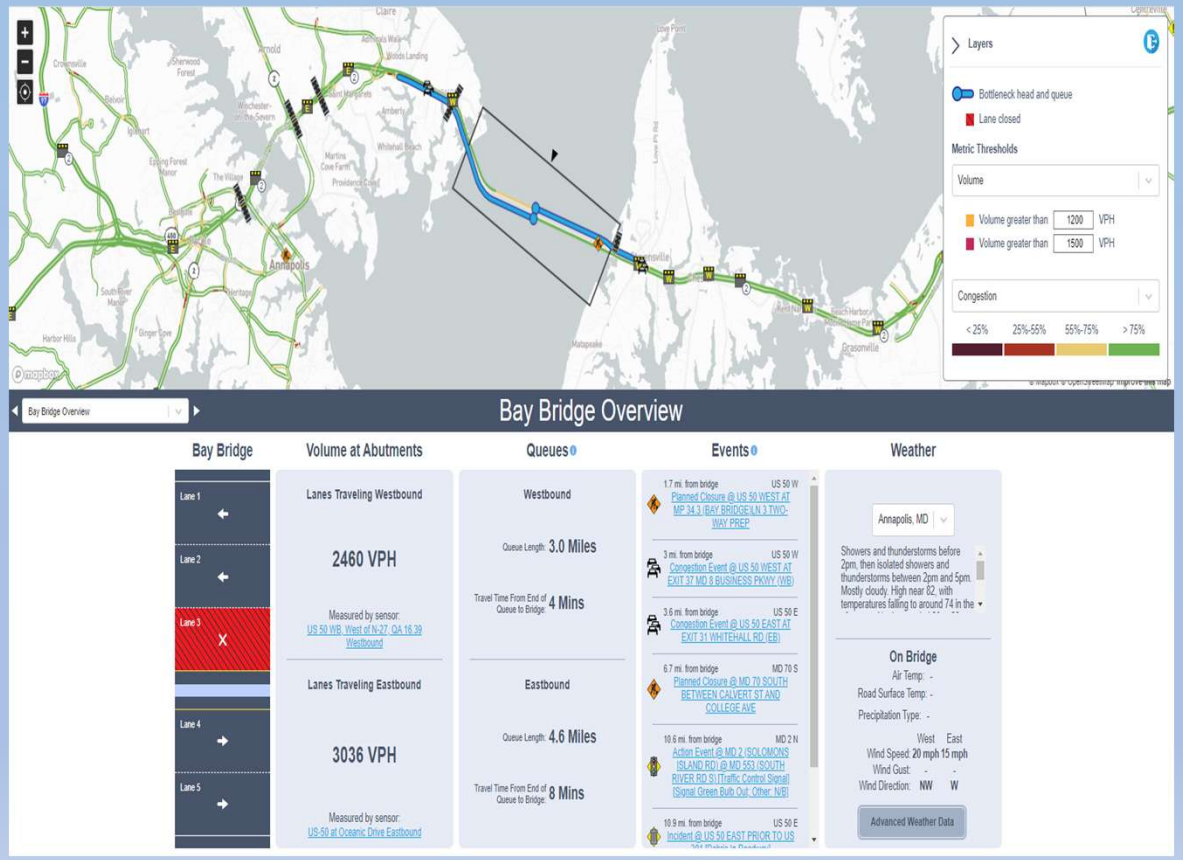
Real time Operations Functions

Map shows:

- Live traffic flow, speeds, and volumes
- Work zones, crashes, and disabled vehicles
- Dynamic message signs and messages
- Weather radar overlays and alerts

Lane diagram:

- Real-time lane status (open, closed, contraflow)
- Color-coded indicators for volume and speed thresholds

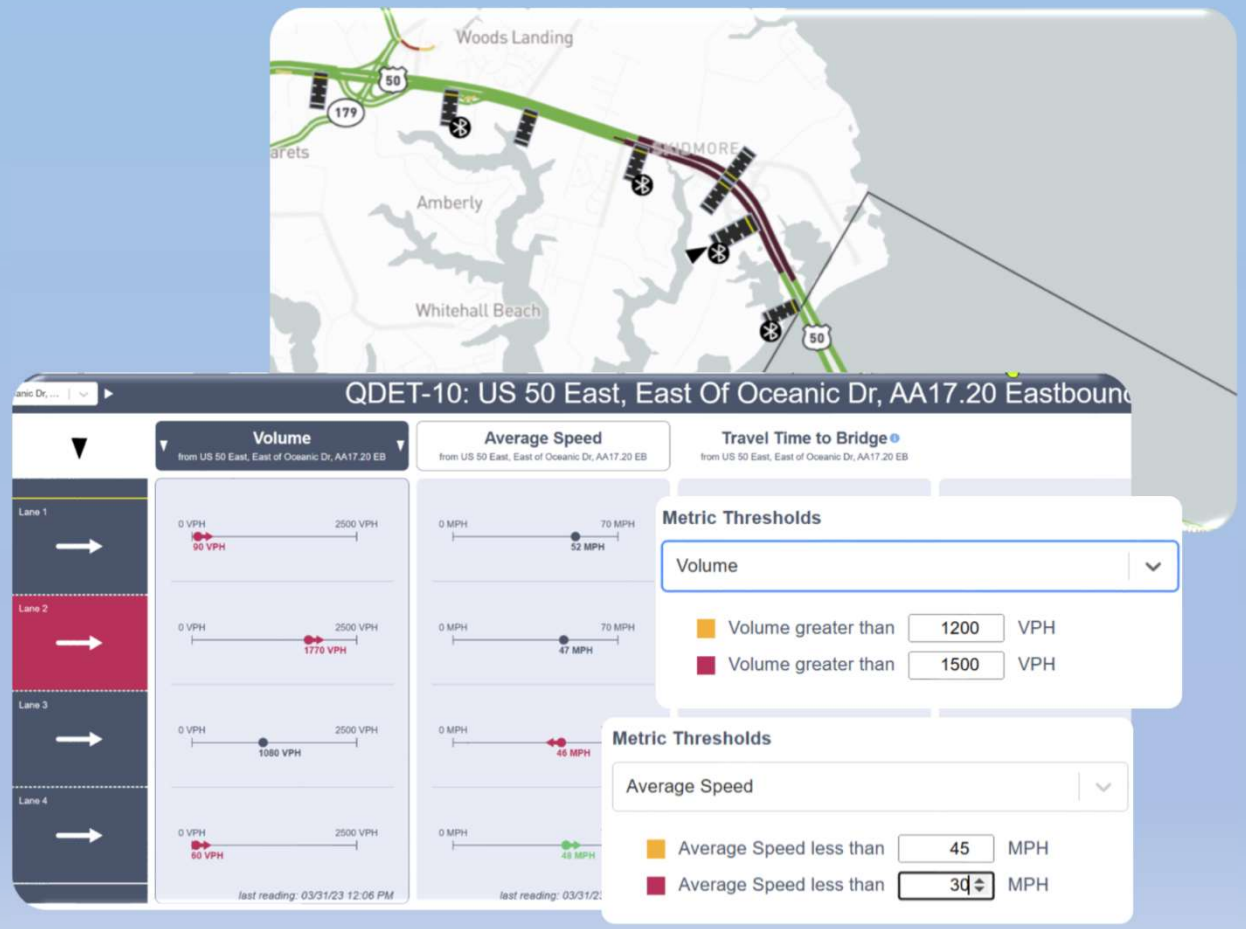


Volume and Speed Insights

Roadside Detector

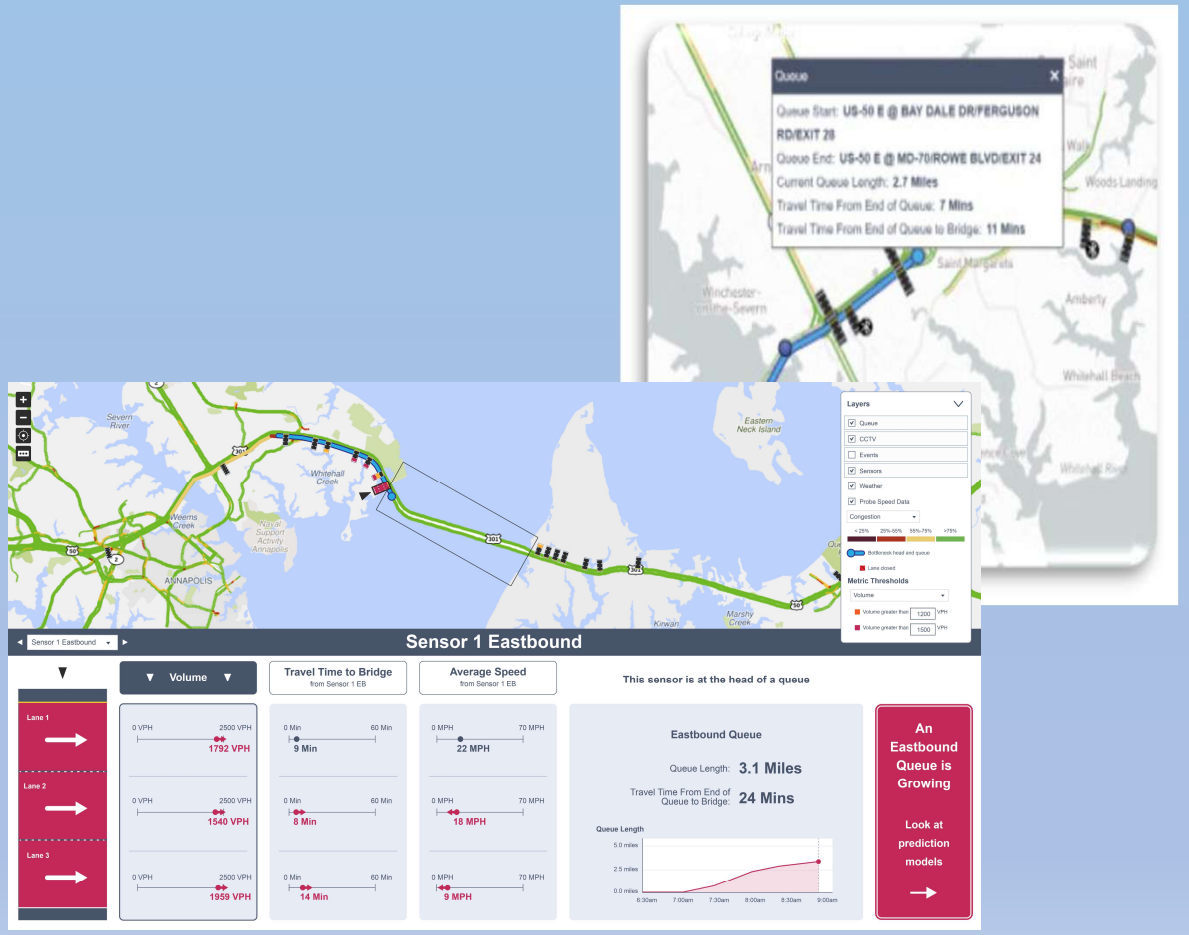
Volume and Speed

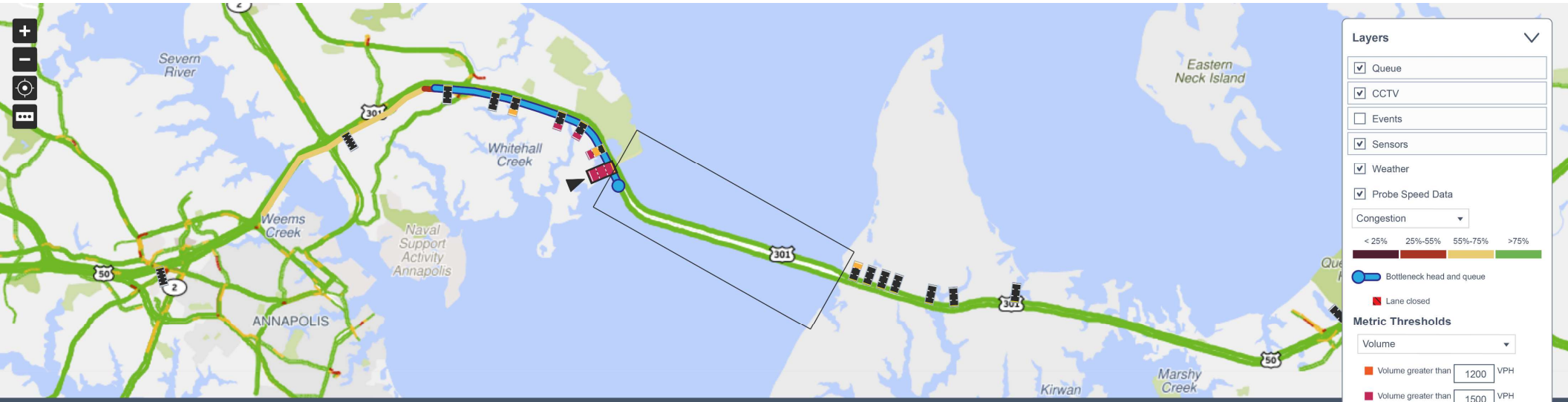
- Traditional radar sensors
- Bluetooth sensors with travel time integration
- Lane specific data visualizations for speed and volume
- Configurable speed and volume legend for lane color rendering



Queue Visualization

- Queue extent and heading
- Identify congestion formation in real time.
- Detects head/tail of slowing traffic queues
- Visualizes queue on map with length, growth rate, predicted clearance
- Enables early lane configuration adjustments
- Helps prevent secondary crashes and congestion escalation





Sensor 1 Eastbound

Sensor 1 Eastbound

Lane 1

Lane 2

Lane 3

Volume

0 VPH — 2500 VPH

1792 VPH

0 VPH — 2500 VPH

1540 VPH

0 VPH — 2500 VPH

1959 VPH

Travel Time to Bridge

from Sensor 1 EB

0 Min — 60 Min

9 Min

0 Min — 60 Min

8 Min

0 Min — 60 Min

14 Min

Average Speed

from Sensor 1 EB

0 MPH — 70 MPH

22 MPH

0 MPH — 70 MPH

18 MPH

0 MPH — 70 MPH

9 MPH

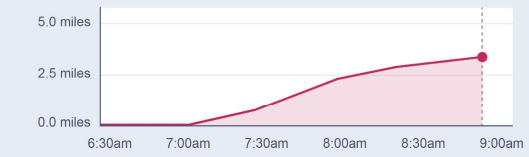
This sensor is at the head of a queue

Eastbound Queue

Queue Length: **3.1 Miles**

Travel Time From End of Queue to Bridge: **24 Mins**

Queue Length

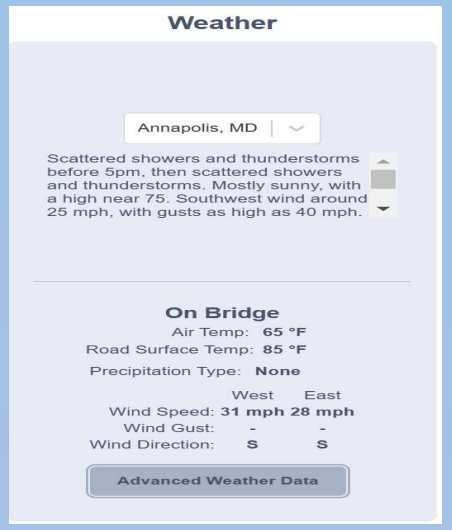


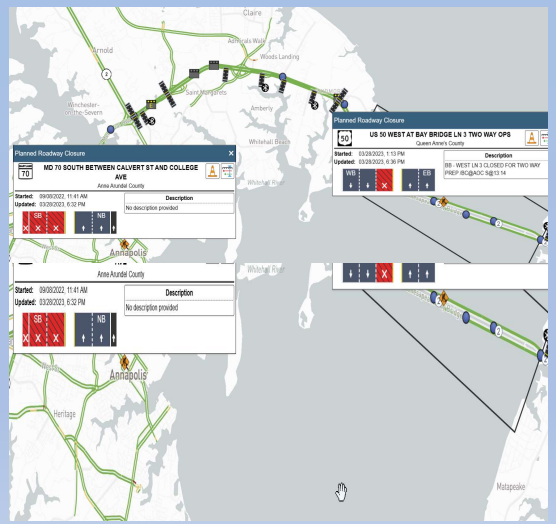
An Eastbound Queue is Growing

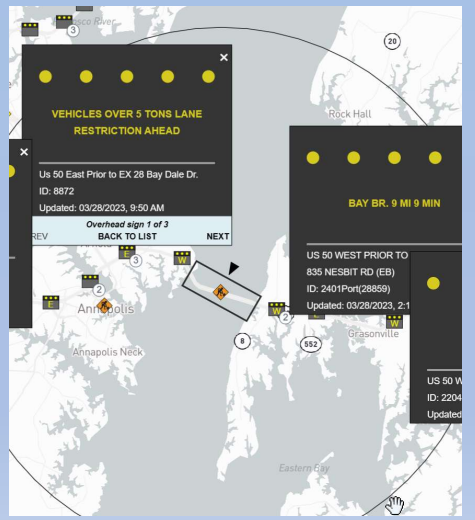
Look at prediction models

Data and Insights Working Together

- Live video feeds for visual confirmation
- Lane-by-lane speed/volume with trend arrows
- Incident icons with pop-up details (location, timeline)
- Weather overlays predicting travel impact
- System updates lane color coding automatically based on thresholds
- Event Integration
- Work zones
  - Crashes
  - Reported congestion
  - Facility issues
  - Roadway obstructions
  - Dynamic message sign messaging



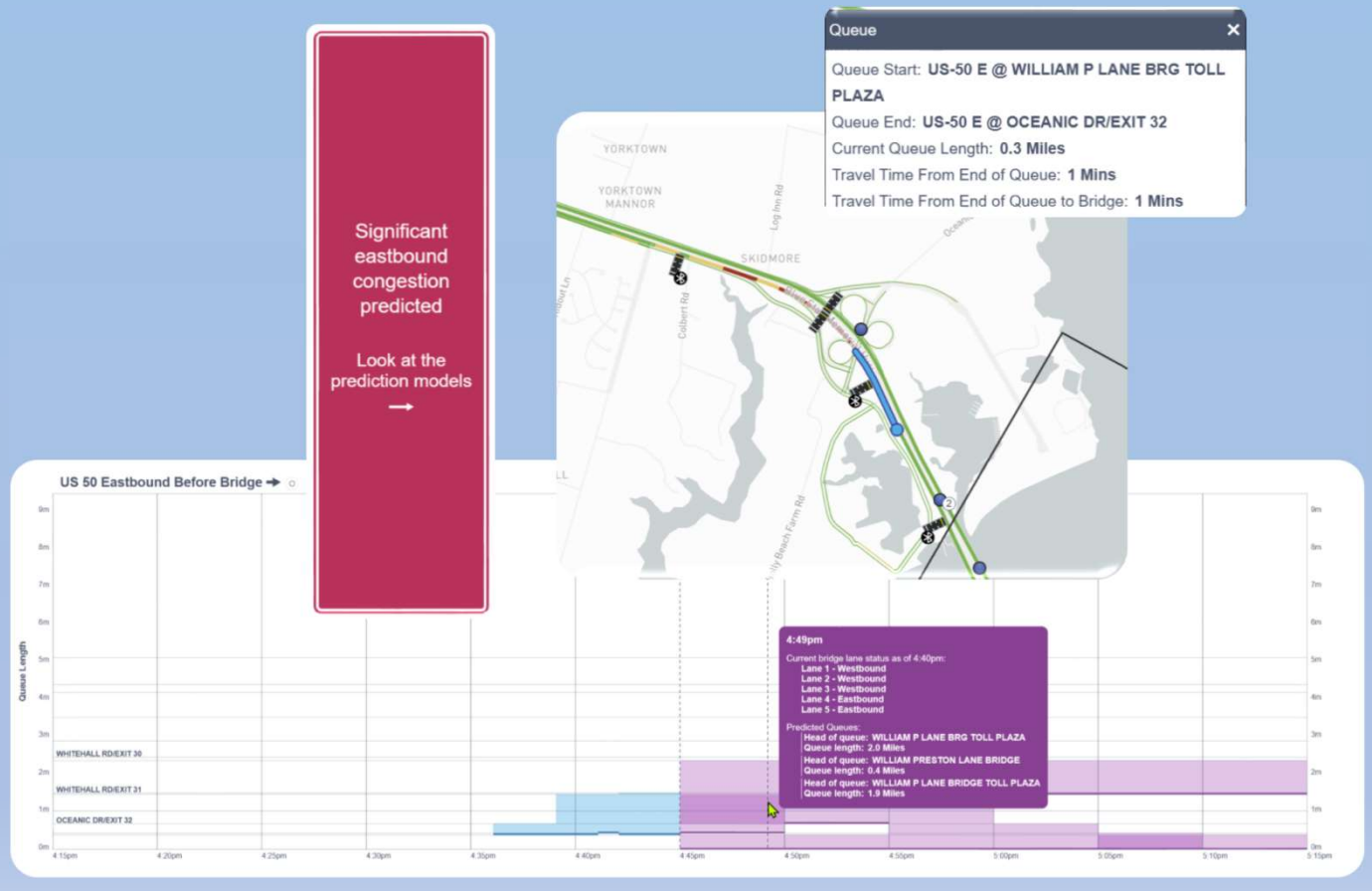




Bridge Web App – Queue Prediction

Queue Prediction

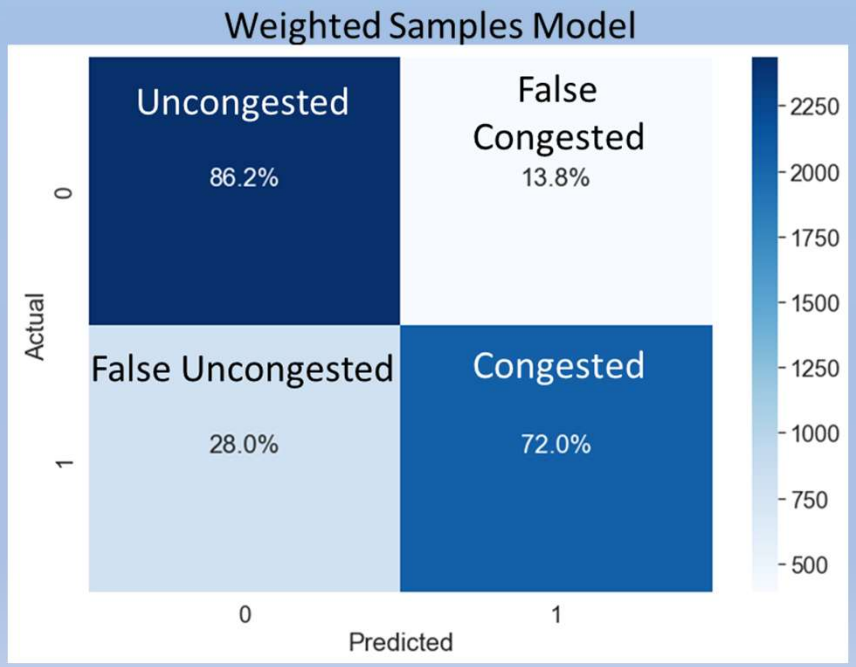
- Hypothetical lane configurations
  - Open/closed/reversed
- Current and Forecasted Queues
  - Up to 30-minute forecast
- Existing queues
- Forecasts with level of certainty



- Defined based on the speed ratio at each TMC:
  - $\frac{Speed}{Free\ Flow\ Speed} < 0.6$ → TMC is congested and part of a queue*
- Predict for 6 consecutive 5-minute time intervals in future
  - $(t+5, t+10, \ldots, t+30)$
- Machine learning model: XGBoost

t	t+30
Uncongested	Congested
Congested	Uncongested
Uncongested	Uncongested
Congested	Congested

0: Uncongested
1: Congested



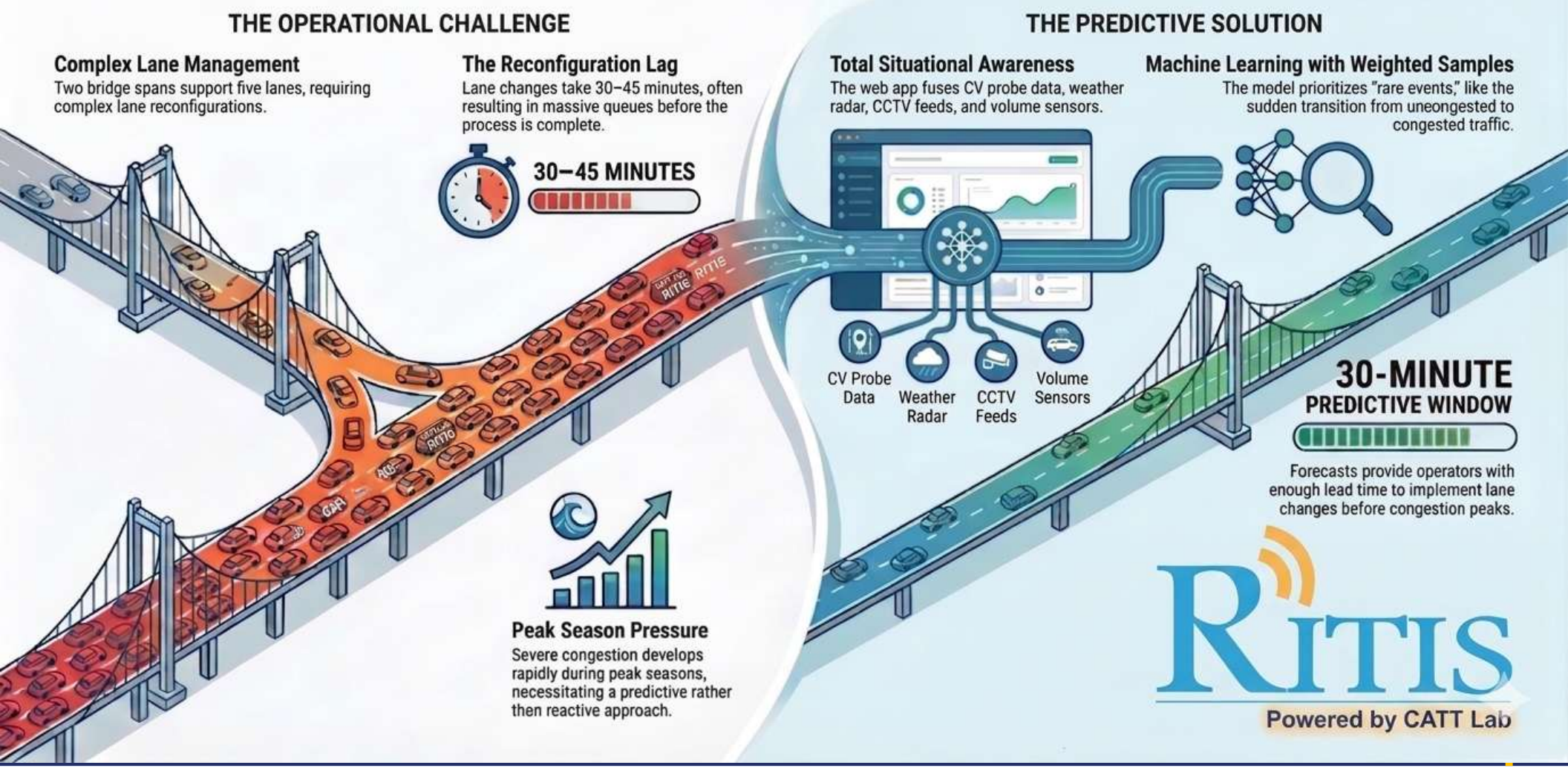
*Integration of sensor data is expected to improve accuracy and potentially, extend the prediction horizon

Next Steps – Phase 2 Goals

- Improved Estimates using new data, new models, etc.
  - Integrate recently installed Bluetooth and volume sensors
    - Expected to improve model accuracy and to extend the prediction horizon
  - Create new interfaces for historical analysis and enhanced prediction outputs


RITIS
Transportation System Status
Data Archive
Personal Traffic Alerts
Welcome!
Incident List
Traffic Map
Incident Overview
Traffic Cameras
RSS Feed
VWS
WZPMA
RITIS Meeting
3802 incidents
360
1
E 16th St
OAK GROVE
Maury St
E Belt Blvd
161
Royall Ave
Oakland
3. Vehicle ID: 122222222
Layer List
Future Events
Flights
Maritime
Incidents and Events
Traffic Cameras
Dynamic Message Signs
Radio Scanners
RWIS
Dashcams (select a segment)
Fleets
FITM Plans
Evacuation Support
Dashcams
TMC: 42004352 | 3 miles | 3 dashcam | 2400 snapshots
1. Vehicle ID: 122222222
6:27:00 PM 1 of 600 Snapshots
Play
2. Vehicle ID: 122222222
6:27:00 PM 1 of 600 Snapshots
Play
3. Vehicle ID: 122222222
6:27:10 PM 1 of 600 Snapshots
Play
Show data for:
Last 10 mins
Today
10:30 AM
11:30 PM
12:30 PM
1:30 PM
2:30 PM
3:30 PM
4:30 PM
5:30 PM
Now
6:30 PM

Predicting the Flow: Machine Learning for Chesapeake Bay Bridge Congestion



THE OPERATIONAL CHALLENGE

Complex Lane Management

Two bridge spans support five lanes, requiring complex lane reconfigurations.

The Reconfiguration Lag

Lane changes take 30–45 minutes, often resulting in massive queues before the process is complete.

30–45 MINUTES

Peak Season Pressure

Severe congestion develops rapidly during peak seasons, necessitating a predictive rather then reactive approach.

THE PREDICTIVE SOLUTION

Total Situational Awareness

The web app fuses CV probe data, weather radar, CCTV feeds, and volume sensors.

CV Probe Data

Weather Radar

CCTV Feeds

Volume Sensors

Machine Learning with Weighted Samples

The model prioritizes "rare events," like the sudden transition from uneongested to congested traffic.

30-MINUTE PREDICTIVE WINDOW

Forecasts provide operators with enough lead time to implement lane changes before congestion peaks.

RITIS

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Thank you!

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