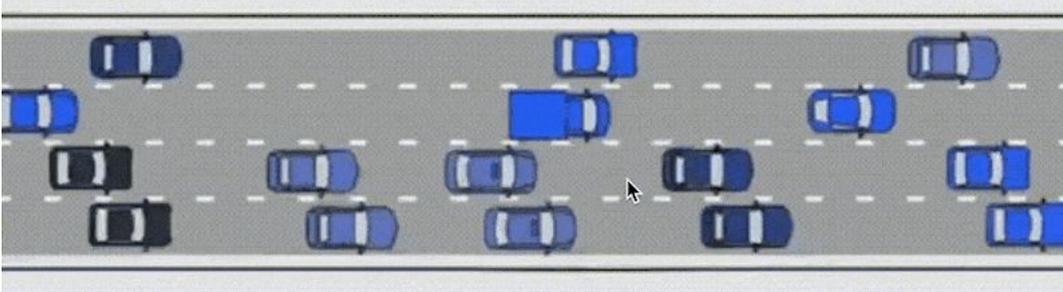


Data-Driven Traffic Reconstruction and Kernel Methods for Identifying Stop-and-Go Congestion

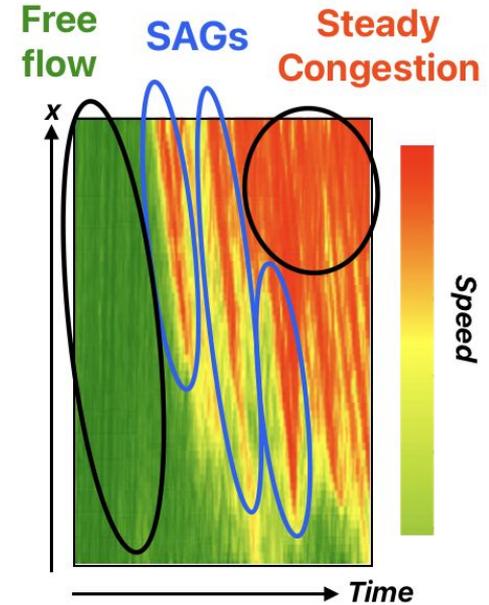
Edgar Ramirez-Sanchez, Shreyaa Raghavan, Prof. Cathy Wu
Massachusetts Institute of Technology



Stop-And-Go Waves (SAGs)



- Also known as phantom jams, oscillations, shock waves
- Cyclic patterns of deceleration followed by acceleration
- Low speed waves propagate backwards (negative slope)
- Triggered by abrupt lane change lanes, car-following behavior and others¹.



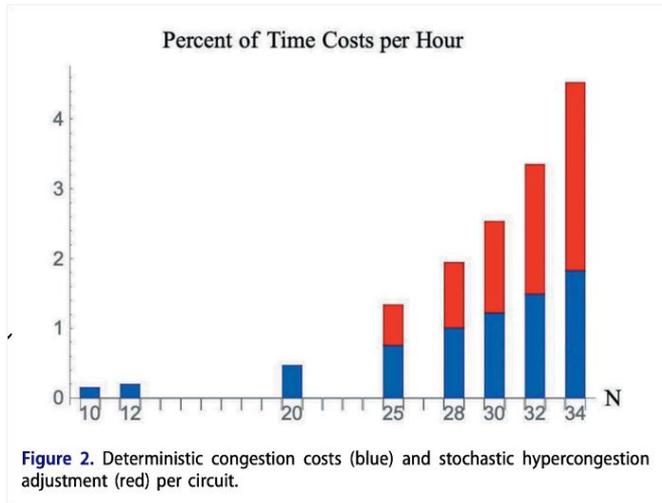
Impact of SAGs

- **Emissions:** Stop and go behavior consumes more energy and fuel
 - **Time:** Wasted time from a non-optimal flow
 - **Safety:** Sudden, unexpected SAG events are safety hazards
-

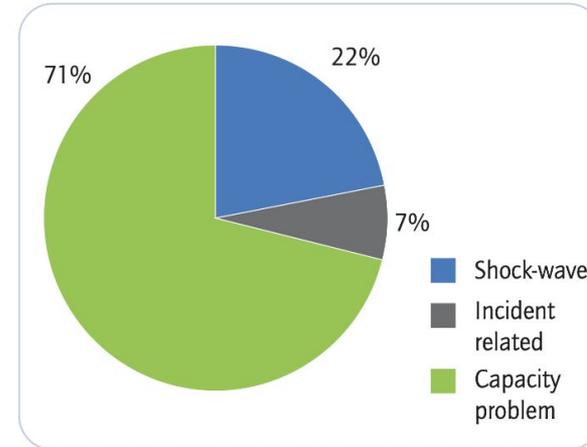
Motivation

SAGs could be responsible for a significant portion of the adverse effects of highway driving

”Ignoring the externality of a phantom jam will underestimate total costs by approximately **50%**” [2]



Is estimated in the Netherlands, roughly **22%** of the traffic jams are shock-wave jams. [3]



[2] Goldmann, K., & Sieg, G. (2020). Economic implications of phantom traffic jams: evidence from traffic experiments. *Transportation Letters*, 12(6), 386-390.

[3] N. M. of Infrastructure and the Environment, ITS in the Netherlands Progress Report 2010 - 2014. 2015.

However, these waves are avoidable!

So, some of the adverse effects/externalities of highway driving are **avoidable**.

Interventions

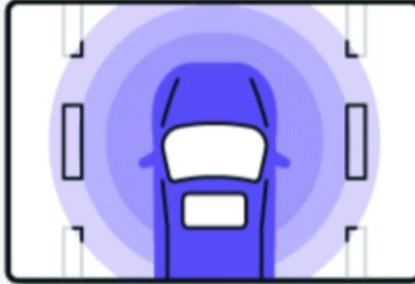
Different technologies to alleviate SAGs, including:

Smart Infrastructure



Connected variable speed limits control and car-following control with vehicle-infrastructure communication to resolve stop-and-go waves (2016)

Control Approaches



Dissipation of stop-and-go waves via control of autonomous vehicles: Field experiments (2018)

Vehicle Communication



Toward Mitigating Phantom Jam Using Vehicle-to-Vehicle Communication (2017)

Main Blocker: Data Availability and Resolution

- Need to identify SAGs to quantify them
 - Lack the rich datasets needed to capture the nuanced vehicles' dynamics
- Data available to researchers and governments are typically sparse and aggregated to a granularity that obscures SAGs.

Limited Rich Data



NGSIM



Widely Available Sparse/Noisy Data



Car

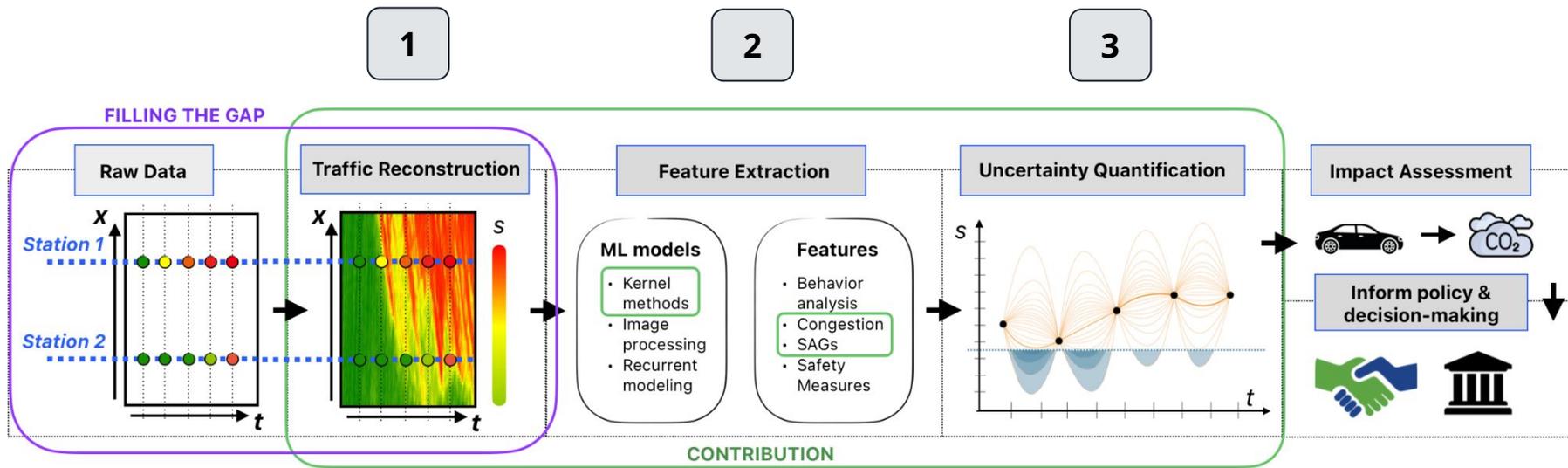


Detectors

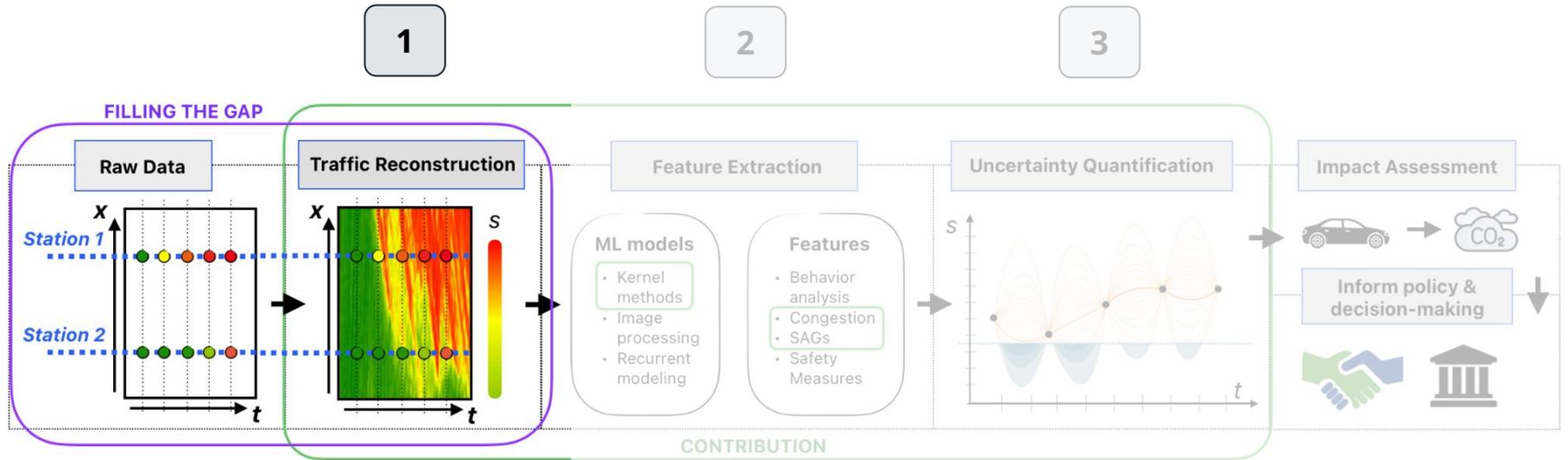
End Goal: A standard **at-scale** pipeline using generally available data to identify and quantify SAGs

Methods

Traffic Feature Identification Pipeline

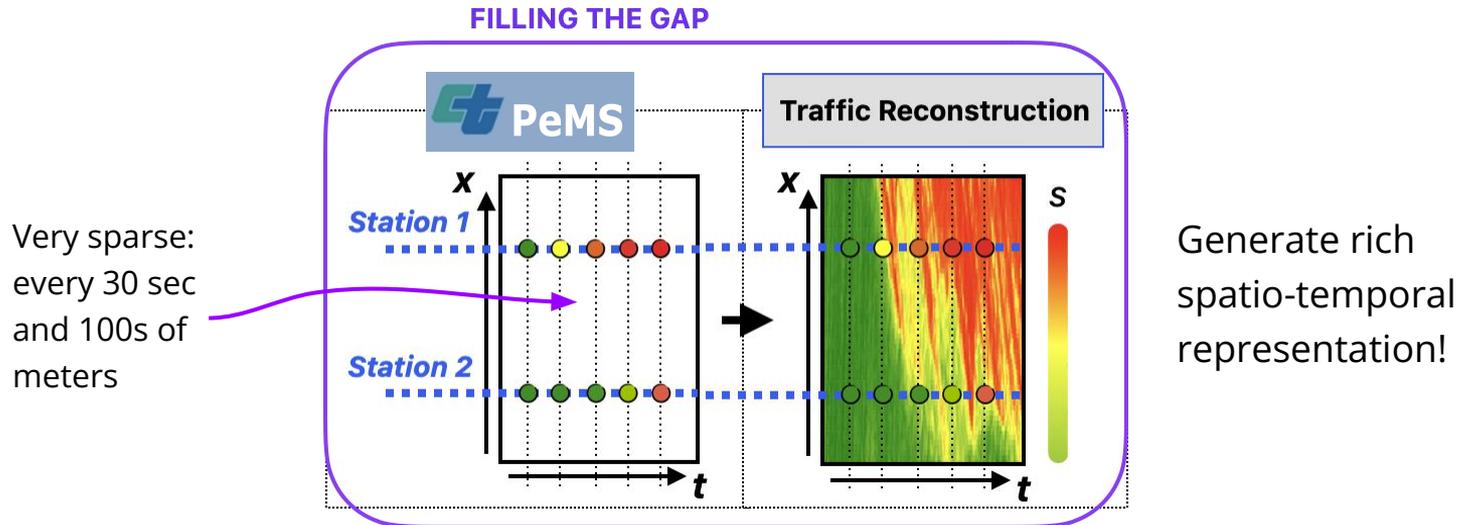


Traffic Feature Identification Pipeline

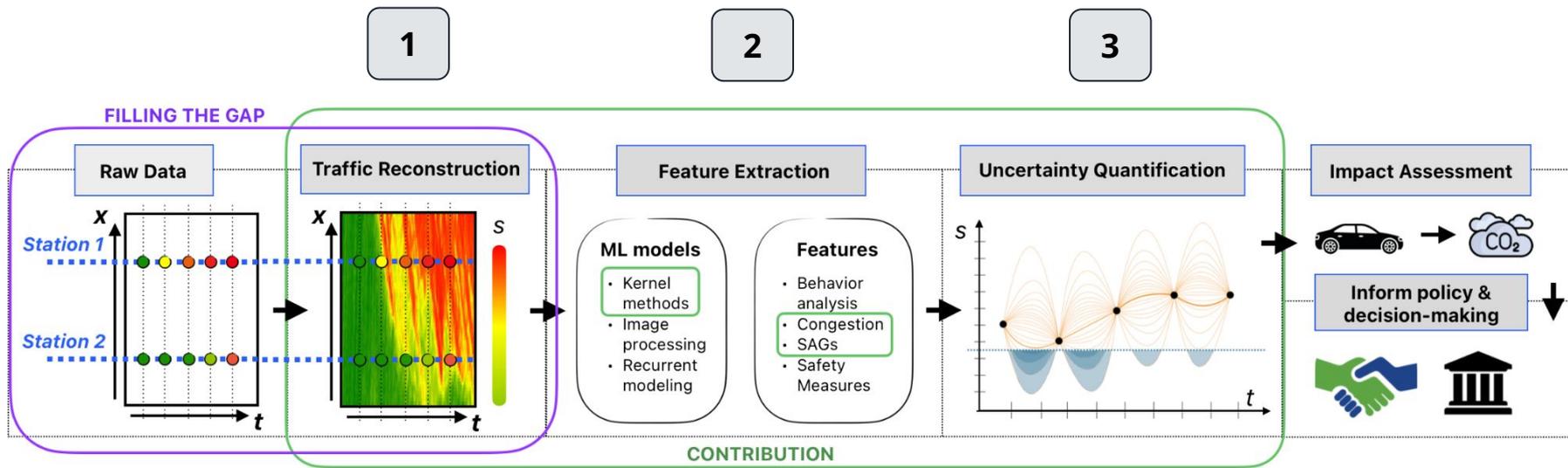


(1) Traffic Reconstruction: Filling the Gap

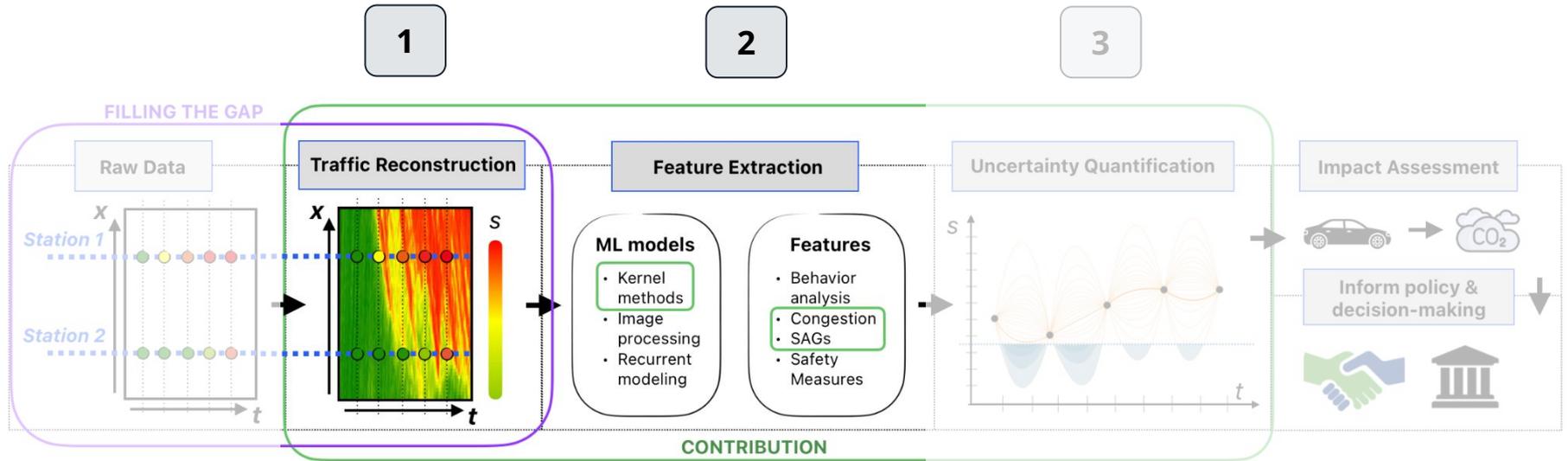
- **Caltrans Performance Measurement System:** ~39,000 induction loop detectors capture traffic flow, occupancy, and speed aggregated **every 30 seconds** on most freeways in CA
- Want to reconstruct trajectories in between
- Uses Intelligent Driver Model (IDM) & SUMO to extrapolate detailed traffic trajectories



Traffic Feature Identification Pipeline



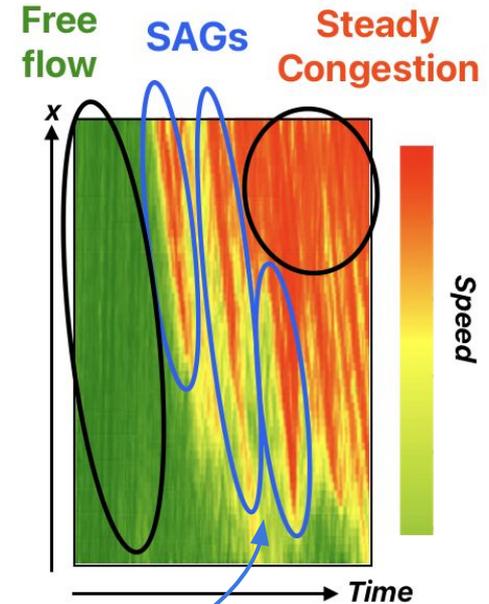
Traffic Feature Identification Pipeline



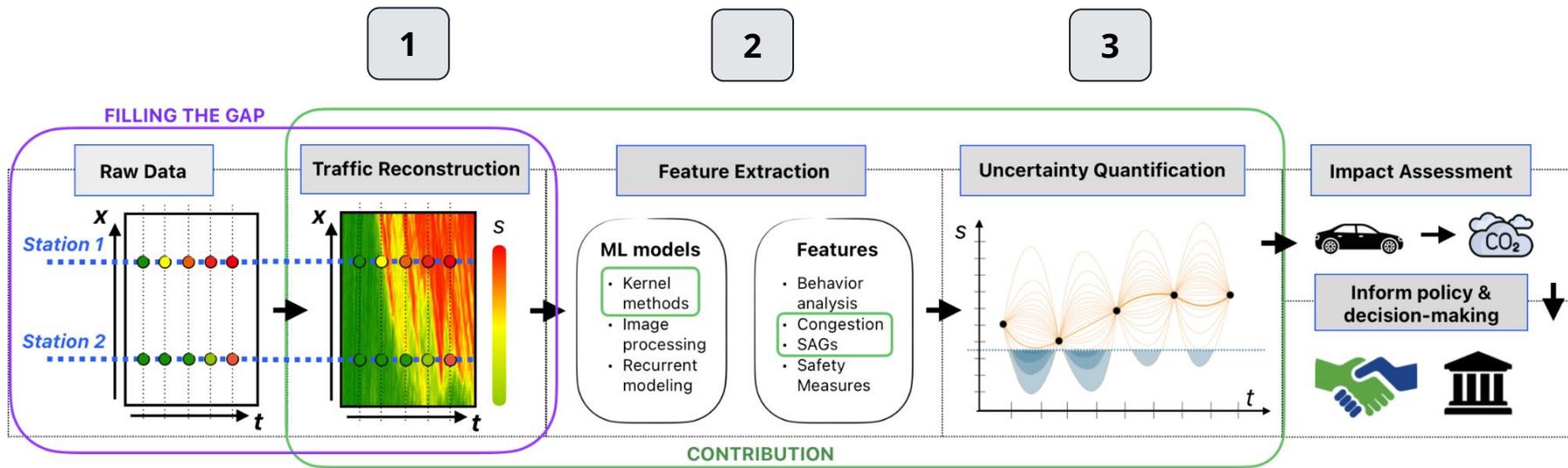
(2) SAG Feature Extraction

- 2D Kernel that captures SAG over **spatiotemporal** domain
 - Dip in speed over time (high \rightarrow low \rightarrow high)
 - Backward propagation over space
 - These known behaviors are well studied
- Based on Sobel operator for edge detection
- Parametrized by width

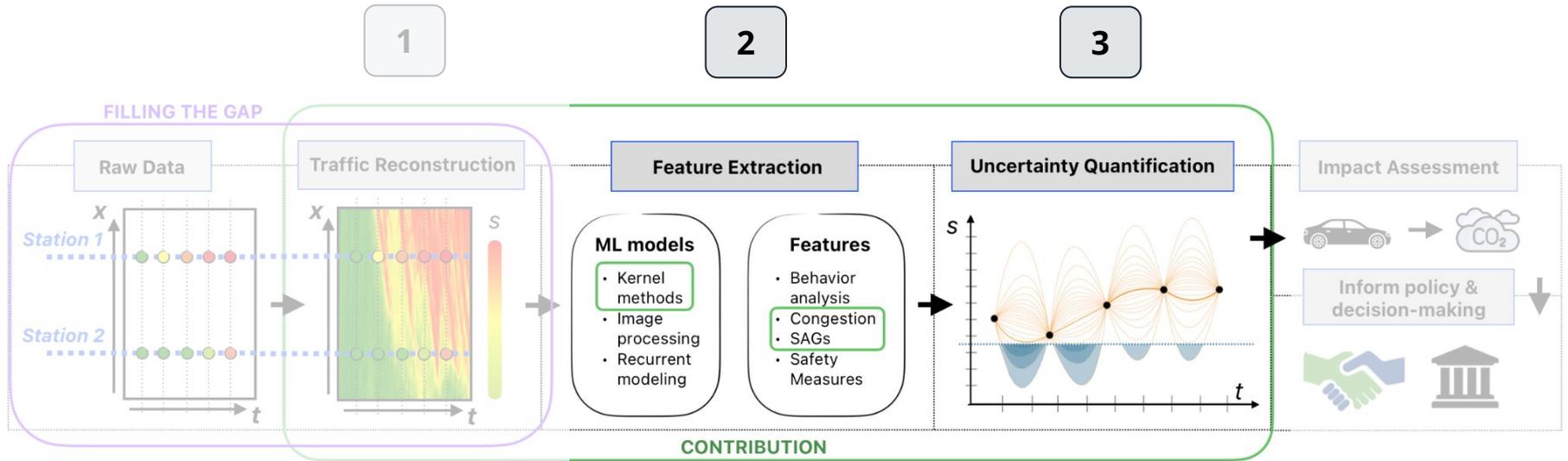
$$K(4) = \begin{bmatrix} 0 & -1 & -1 & -1 & -1 & 0 & 2 & 2 \\ 2 & 0 & -1 & -1 & -1 & -1 & 0 & 2 \\ 2 & 2 & 0 & -1 & -1 & -1 & -1 & 0 \end{bmatrix}$$



Traffic Feature Identification Pipeline

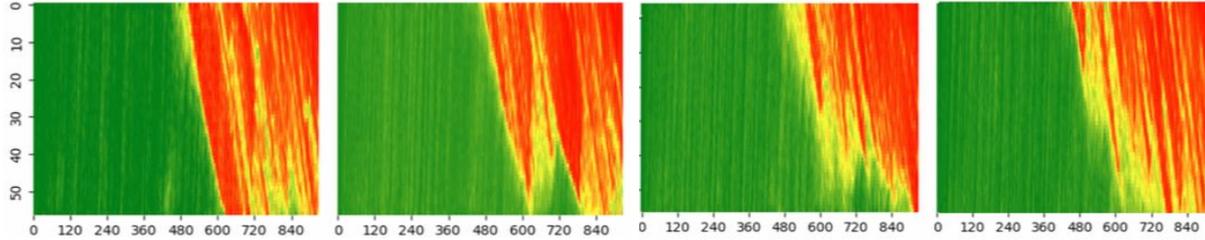


Traffic Feature Identification Pipeline

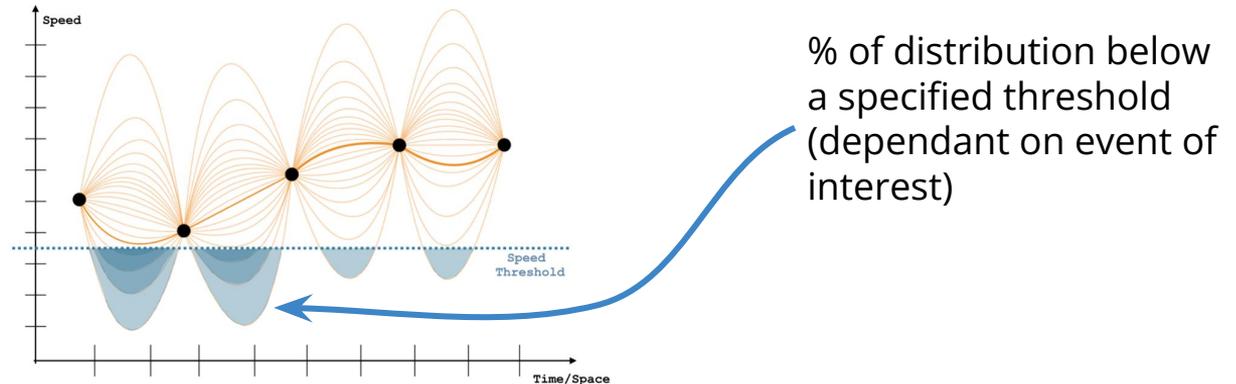


(3) Uncertainty Quantification

- Variations across reconstructions



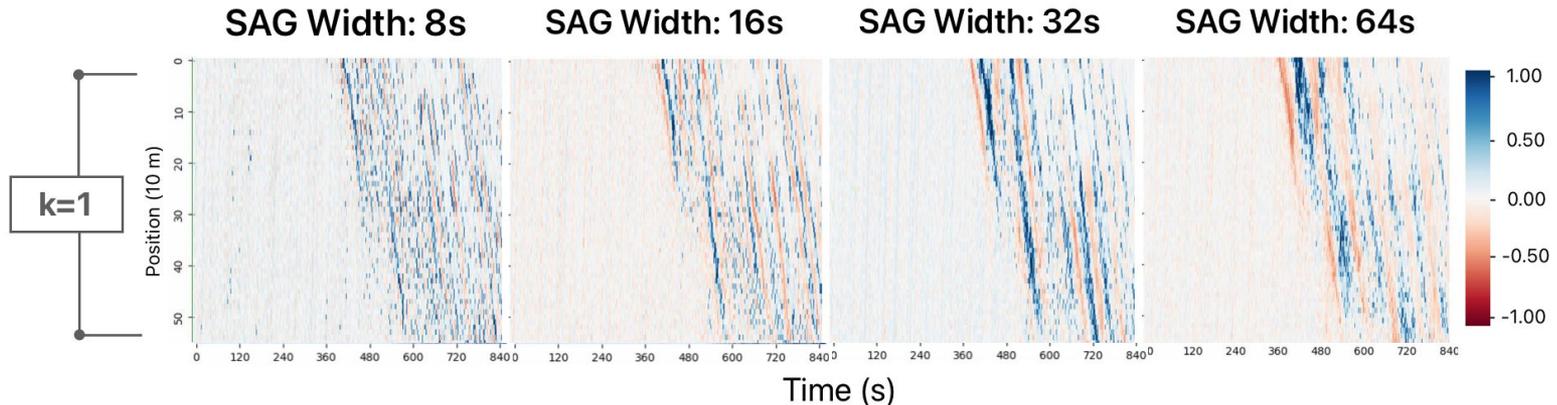
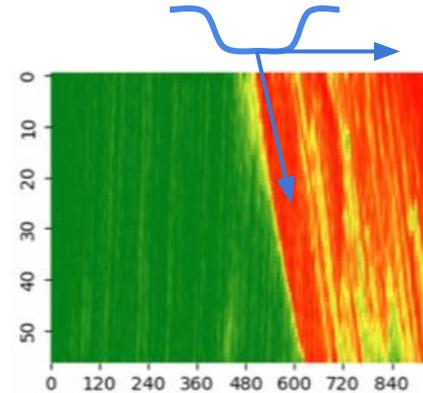
- Bootstrapping:** Treat traffic reconstruction as a distribution sampler, and run k times
- Want to estimate $p_A(A|t, x)$: probability of event A at time t and position x



Results

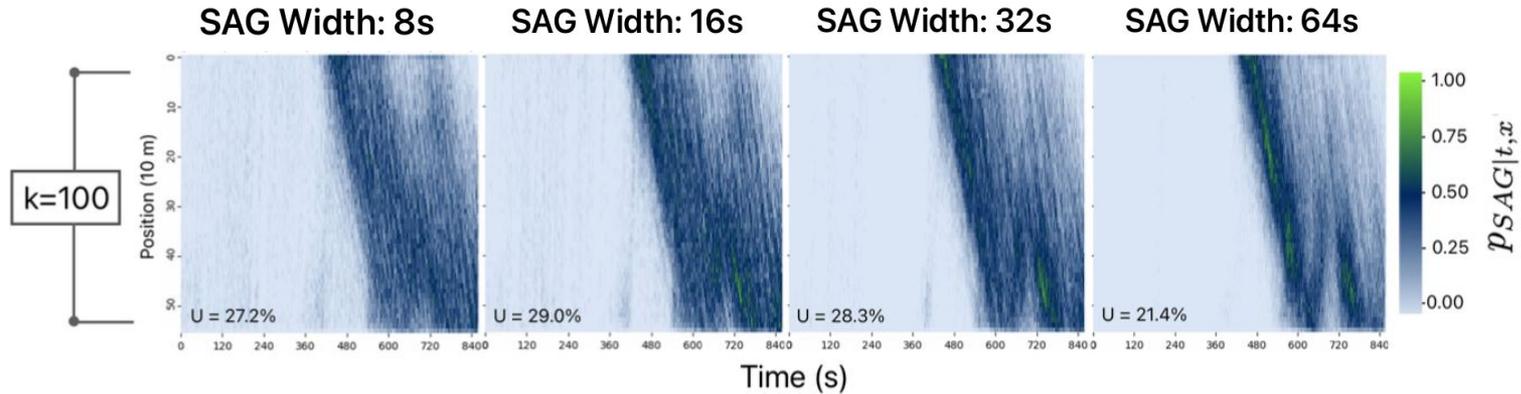
Experimental Results

- Reconstructed LA County between 11:15-11:30 am for a 0.5 km stretch on the 110-N freeway
- Convolve kernel on time-space diagram
- Result: **Kernel Activation Value**
 - How strongly behavior matches kernel



Implications

High probability regions of SAGs



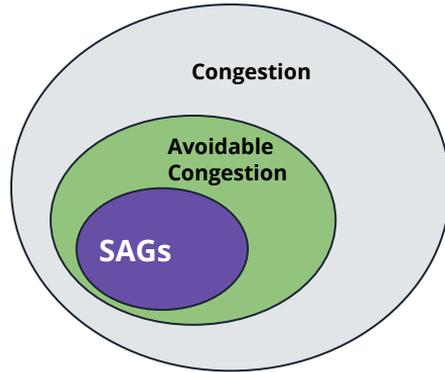
- From individual samples to a distribution
- Local SAG detection
- Map of avoidable congestion & social cost - opportunities for intervention

Conclusions

- Stop-and-go wave mitigation is a significant opportunity for making highway driving more sustainable
- Traffic reconstruction is a valuable method to get full/rich information from sparse data
 - Needs to be validated more rigorously
- Can robustly detect SAGs using sampling & UQ
- Kernels show potential for more complex ML methods to leverage this data



Goals

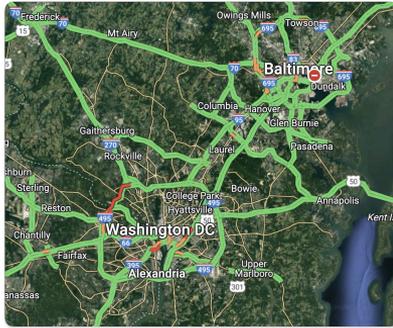


Quantify the opportunity



Mobilize efforts

New investment prioritization
Momentum from academia
Market opportunities for industry



Detect when and where they happen



Guide efforts

Empowers ML pipelines, smart infrastructure, and decision-makers, to design and deploy targeted interventions.

Thank You!
