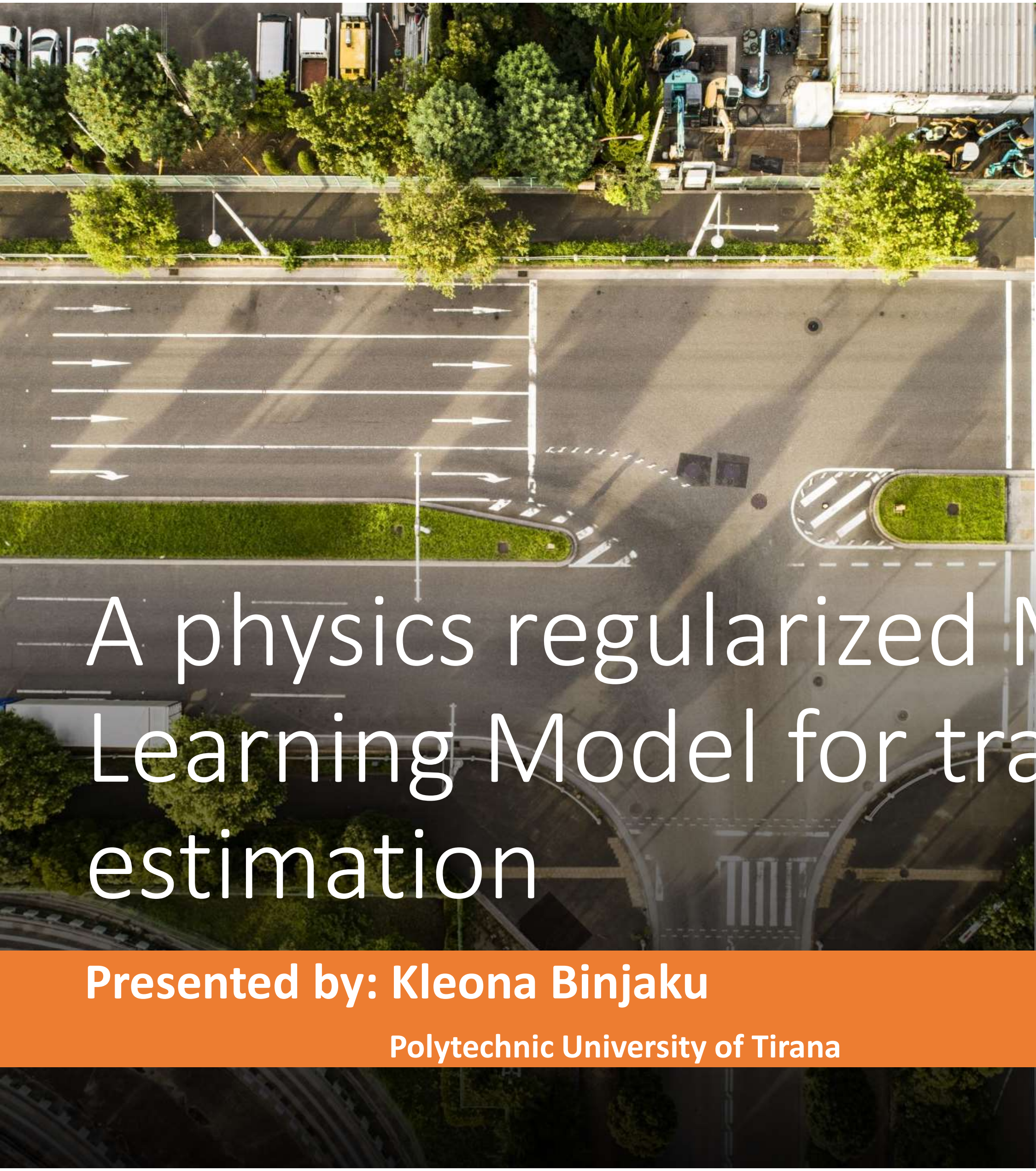


A physics regularized Machine Learning Model for traffic state estimation

Presented by: Kleona Binjaku

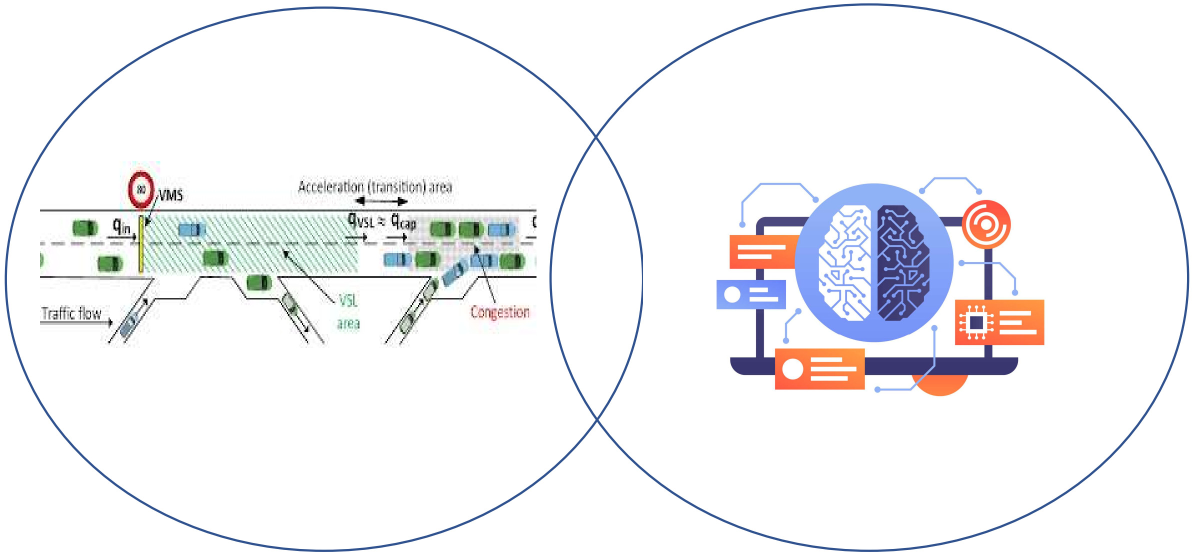
Polytechnic University of Tirana

Outline

- Research proposal and Motivation
- Traffic model used
- ML algorithm used
- Hybrid model
- Algorithm
- Case study
- Results

Research proposal

CREATE A HYBRID MODEL



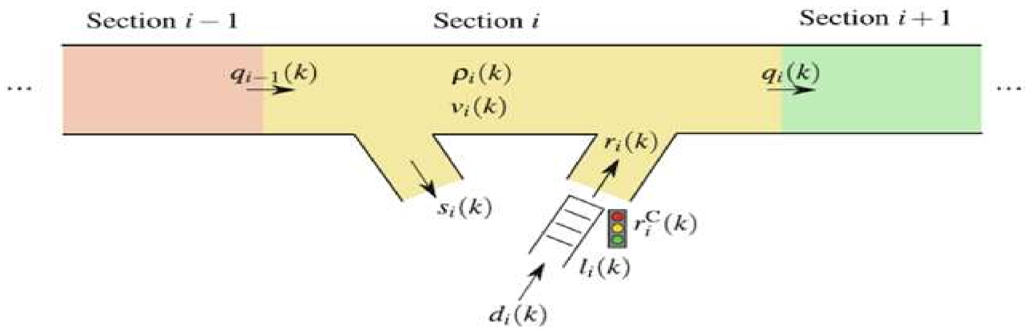
classical traffic models **Machine Learning models**

Motivation

Classical models	ML models
strong assumptions	highly depend on the data quality
require effort in parameter calibrations	results are usually hard to be interpreted
fall short of capturing data uncertainties	

Get the best of both worlds!

METANET



$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i \lambda_i}[q_{i-1}(k) - q_i(k) + r_i(k) - s_i(k)]$$

$$v_i(k+1) = v_i(k) + \frac{T}{\tau}[V_i(k) - v_i(k)] + \frac{T}{L_i} v_i(k)[v_{i-1}(k) - v_i(k)] - \frac{\upsilon T[\bar{\rho}_{i+1}(k) - \bar{\rho}_i(k)]}{\tau L_i[\bar{\rho}_i(k)+\chi]} - \Delta T \frac{v_i(k) r_i(k)}{L_i[\bar{\rho}_i(k)+\chi]}$$

$$q_i(k) = \rho_i(k).\, v_i(k).\, \lambda_i$$

$\tau, \chi, \Delta, \upsilon$ - model parameters

v_i^f - free flow speed
ρ_i^{max} - jam density.

Steady state speed-density relation: $V_i(k) = V\big(\bar{\rho}_i(k)\big) = v_i^f.\,[1 - (\frac{\bar{\rho}_i(k)}{\rho_i^{max}})^l]^m$

Gaussian Processes (GP)

- Framework for non-parametric regression
- Model the data points as jointly Gaussian

$$y_1, \ldots, y_n \mid x_1, \ldots, x_n \sim N(\mu, \Sigma)$$

- Predictive model for an input trajectory

$$p(f(x^*) \mid x^*, X, Y) = N(\mu(x^*), \sigma(x^*))$$

provides a mean and a predictive variance:

$$\mu(x^*) = K_*^T (K + \tau^{-1} I)^{-1} Y$$

$$\sigma(x^*) = K(x^*, x^*) - K_*^T (K + \tau^{-1} I)^{-1} K_*$$

where $K_* = [K(x^*, x_1) \; \ldots. \; K(x^*, x_n)]^T$ is the kernel

Hybrid model

Use METANET equations in the regularization process of ML algorithm

Latent Force Functions – to encode physics into GP

Evidence Lower Bound (ELBO) of a posterior distribution

Objective function

- Derive the objective function from posterior probability

$$\max L = \sum_{i=1}^{d'} \log\left[N([Y]_i \mid [\mu_f]_i, [\sigma_f]_i\right] + \sum_{w=1}^{W} \Upsilon_w E_{p(Z)} E_{p(\mu_{f_w} \mid Z,X,Y)} [\log\left[N\left(\Phi_{\mu_{f_w}} \;\middle|\; \mu_{g_w}, \sigma_{g_w}\right)\right]]$$

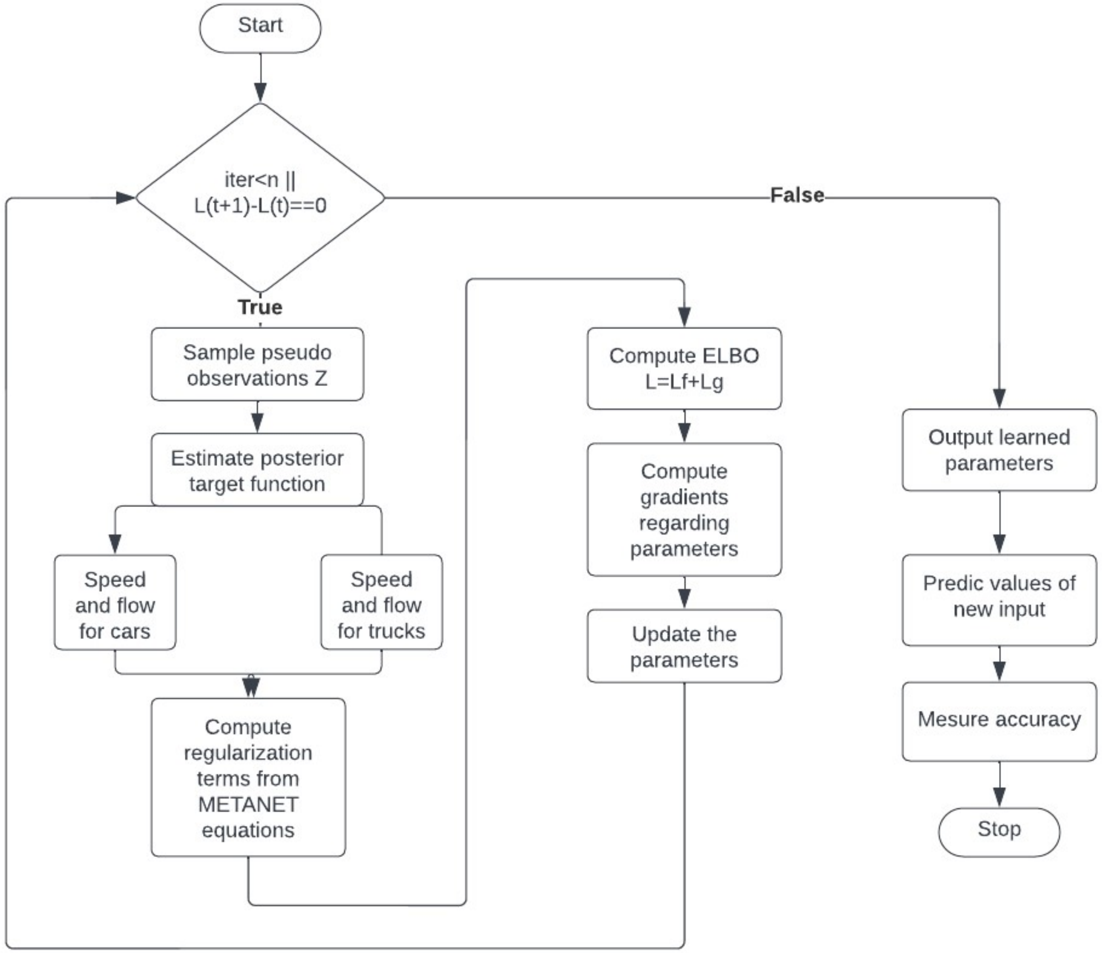
$$\sigma_f = K_f(X,X) + \tau^{-1} I$$

$$\sigma_g = K_g(Z,Z)$$

$$\Theta = [\theta_f \ \theta_g]^T = [\bar{\tau} \ \ \eta \ \ \tau \ \ \nu \ \ \delta \ \ \kappa \ \ \nu_f \ \ \rho_{cr} \ \ \alpha \ ]^T$$

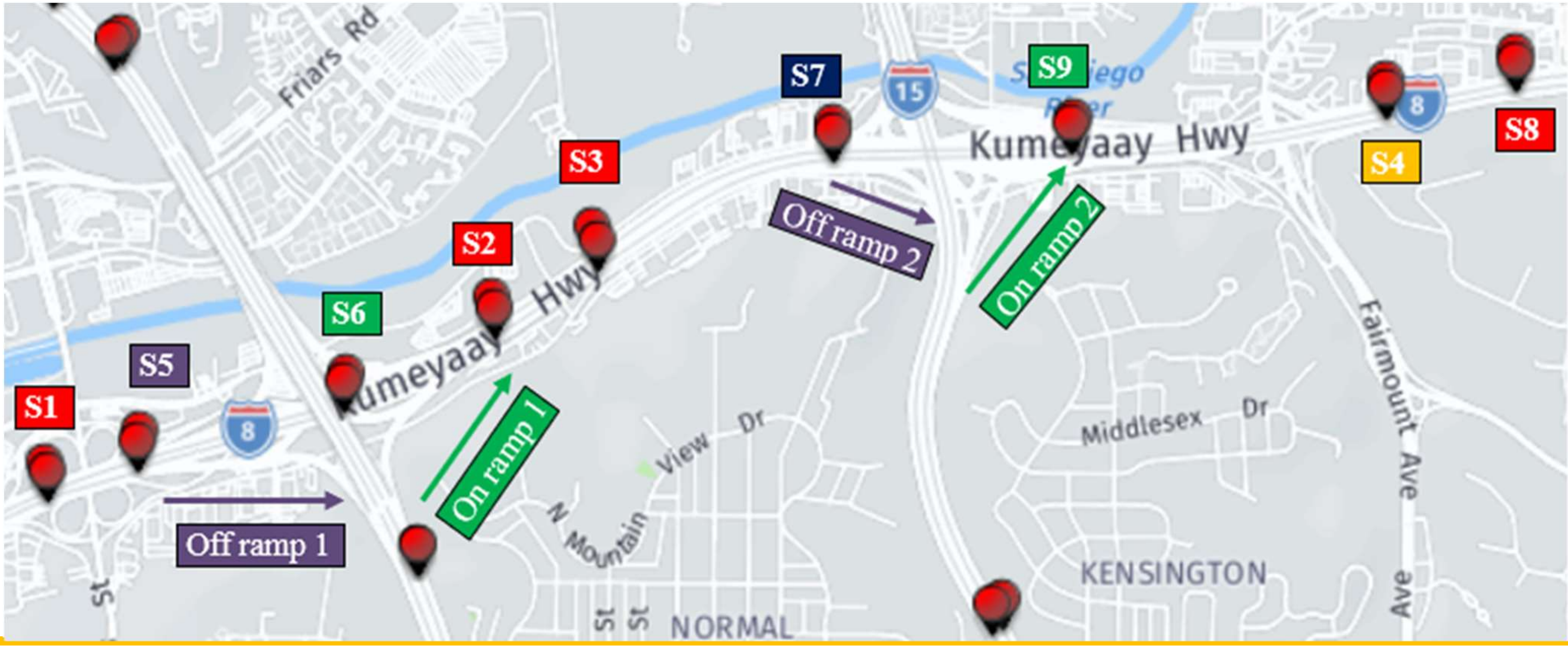
- Objective function has two parts:
  I. posterior probability where input data are the observed ones
  II. posterior probability where input data are the pseudo-observations

Algorithm



Start
iter<n ||
L(t+1)-L(t)==0
True
False
Sample pseudo observations Z
Estimate posterior target function
Speed and flow for cars
Speed and flow for trucks
Compute regularization terms from METANET equations
Compute ELBO L=Lf+Lg
Compute gradients regarding parameters
Update the parameters
Output learned parameters
Predic values of new input
Mesure accuracy
Stop

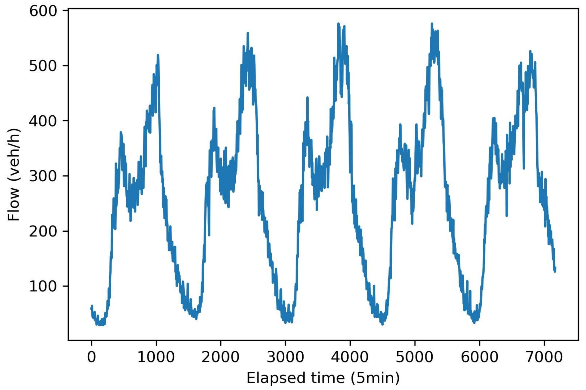
Case study

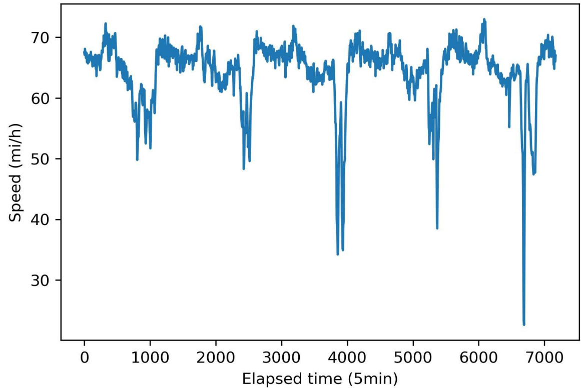


S1
S2
S3
S4
S5
S6
S7
S8
S9
Off ramp 1
Off ramp 2
On ramp 1
On ramp 2
Kumeyaay Hwy
Friars Rd
Middlesex Dr
Fairmount Ave
KENSINGTON
NORMAL

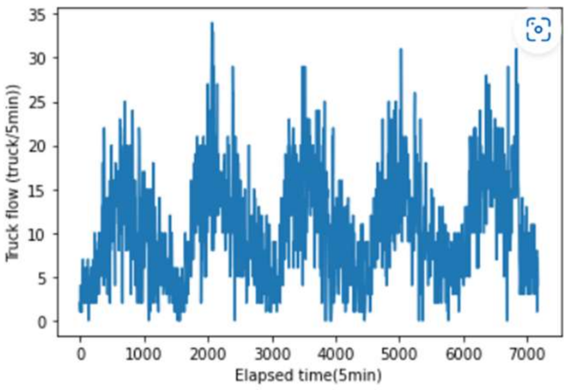
Input data (two-class case)

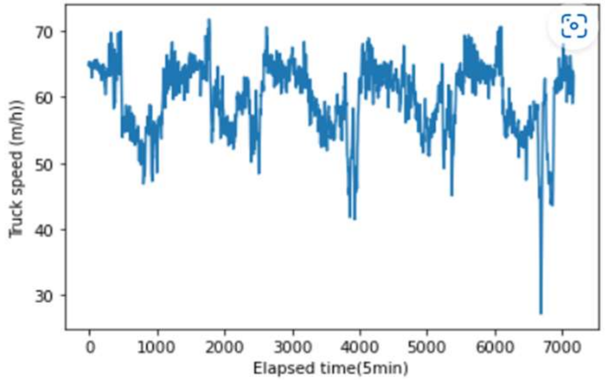
Passenger vehicles





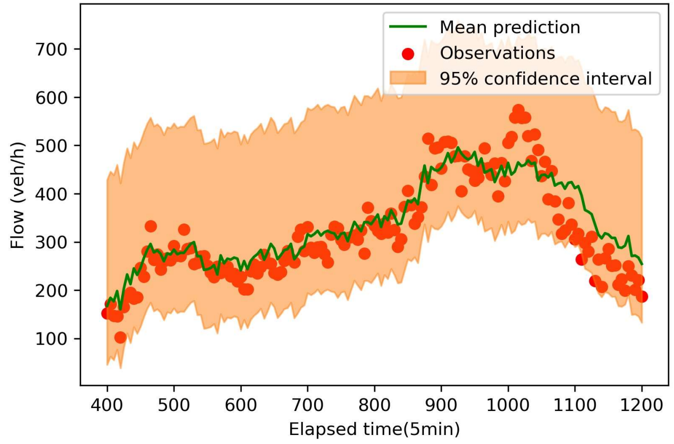
Heavy-duty vehicles

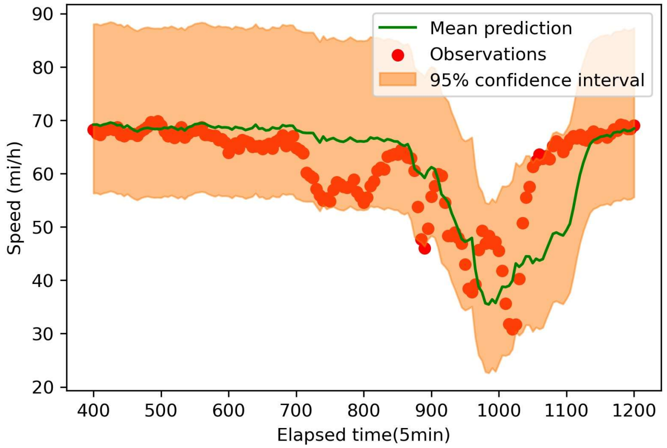




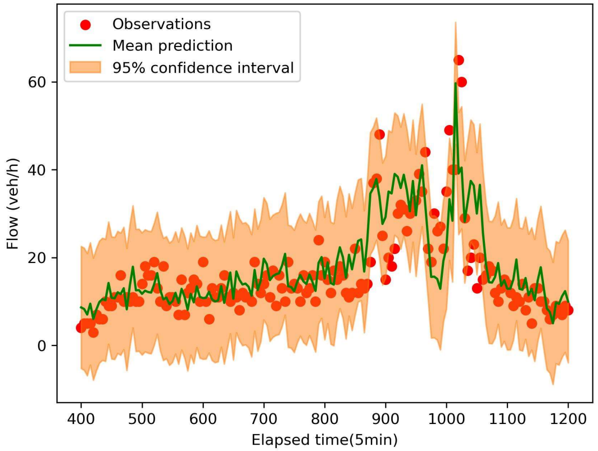
Results

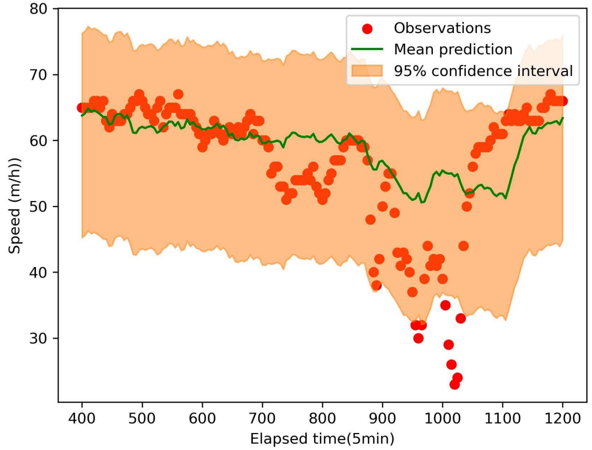
Passenger vehicles





Heavy-duty vehicles





Results comparison

Method	MAPE flow (passenger vehicles)	MAPE speed (passenger vehicles)	MAPE flow (heavy-duty vehicles)	MAPE speed (heavy-duty vehicles)
Pure ML	0.265	0.115	0.5	0.124
Pure multi-class METANET	0.173	0.13	0.45	0.11
Hybrid model	0.128	0.08	0.27	0.07

Conclusions

- We proposed the development of a Machine Learning component capable of approximating a multi-class METANET model
- We can use this hybrid model to predict the traffic state in an MPC-like control scheme

- The results of the hybrid model in the multi-class case show the improvement of the prediction accuracy comparing to the pure ML and pure multi-class METANET
- The results motivate us to continue our study considering other components of the highway or studying other ML algorithms.

Thank you!