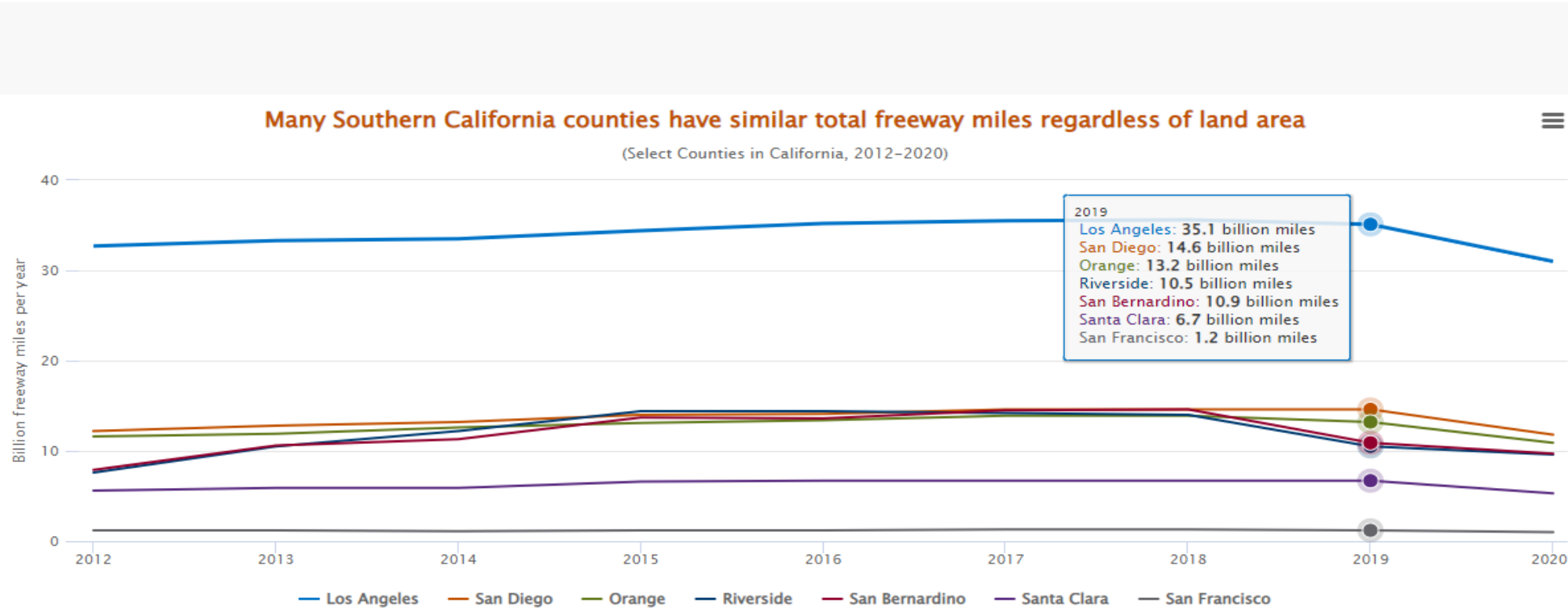




AI assisted Ramp Metering  
February 2024

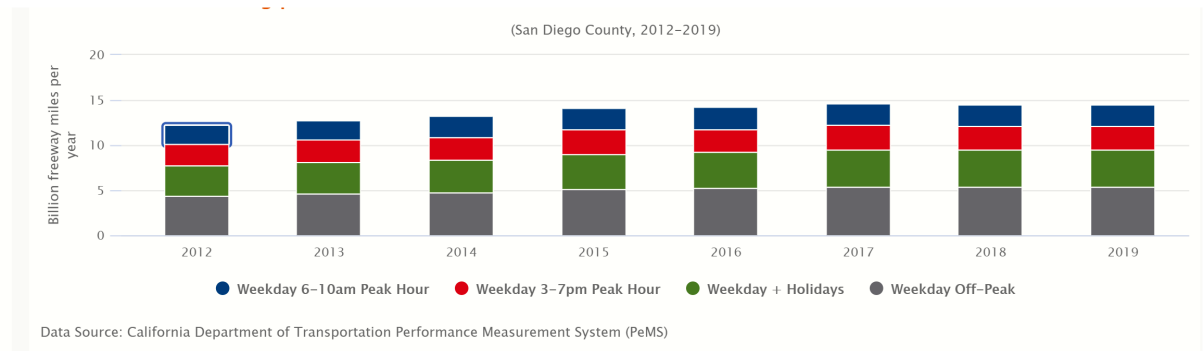
Anush Badii

# This is the number of freeway miles we travel



Data Source: California Department of Transportation Performance Measurement System (PeMS), 2021

# Statistics for San Diego County



2019

**Weekday 6-10am Peak Hour: 2.4 billion miles**

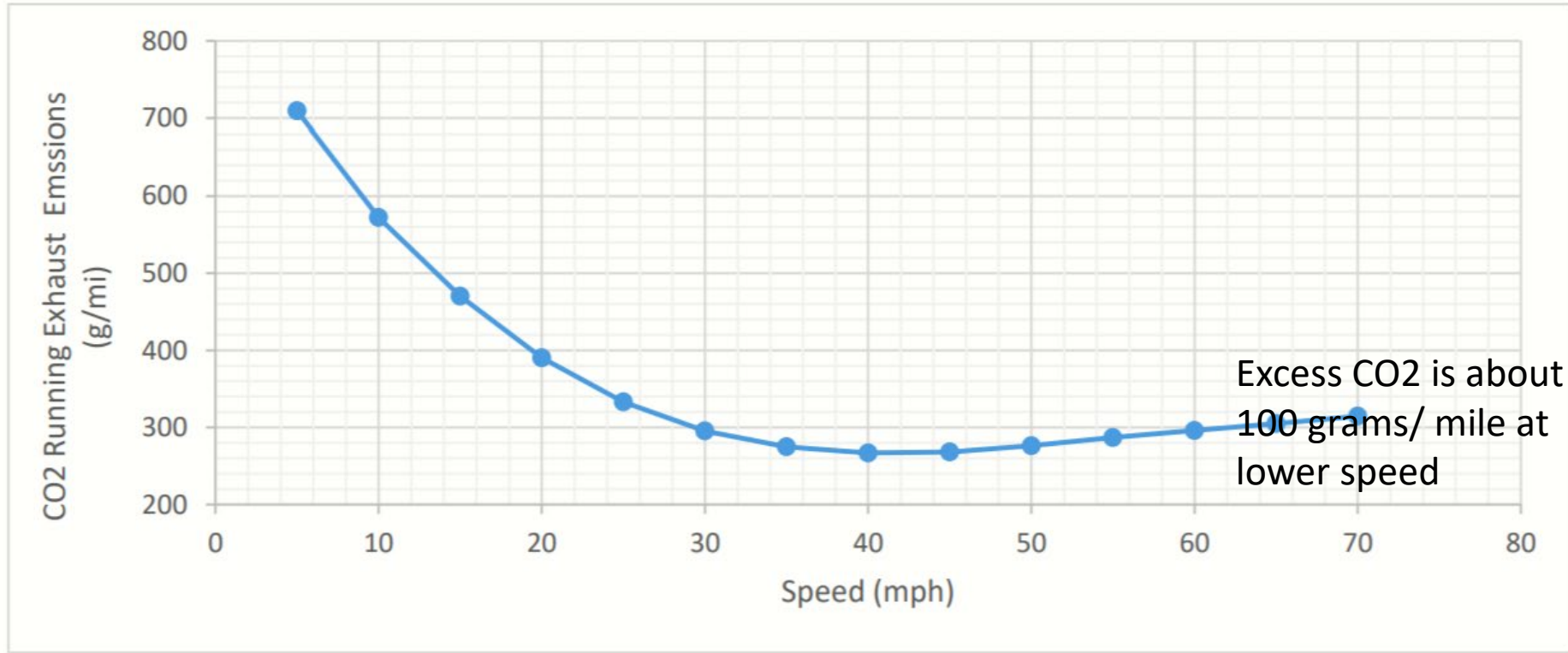
**Weekday 3-7pm Peak Hour: 2.6 billion miles**

**Weekday + Holidays: 4.1 billion miles**

**Weekday Off-Peak: 5.4 billion miles**

# This is how much Green House Gas we produce

Figure 7. California Average Light Duty Vehicle CO<sub>2</sub> Emission Factors by Speed, 2018



Source: EMFAC 2017



Excess CO2 is about 100 grams/ mile at lower speed

Or 150 shiploads of CO2



# Health Hazards and inequity

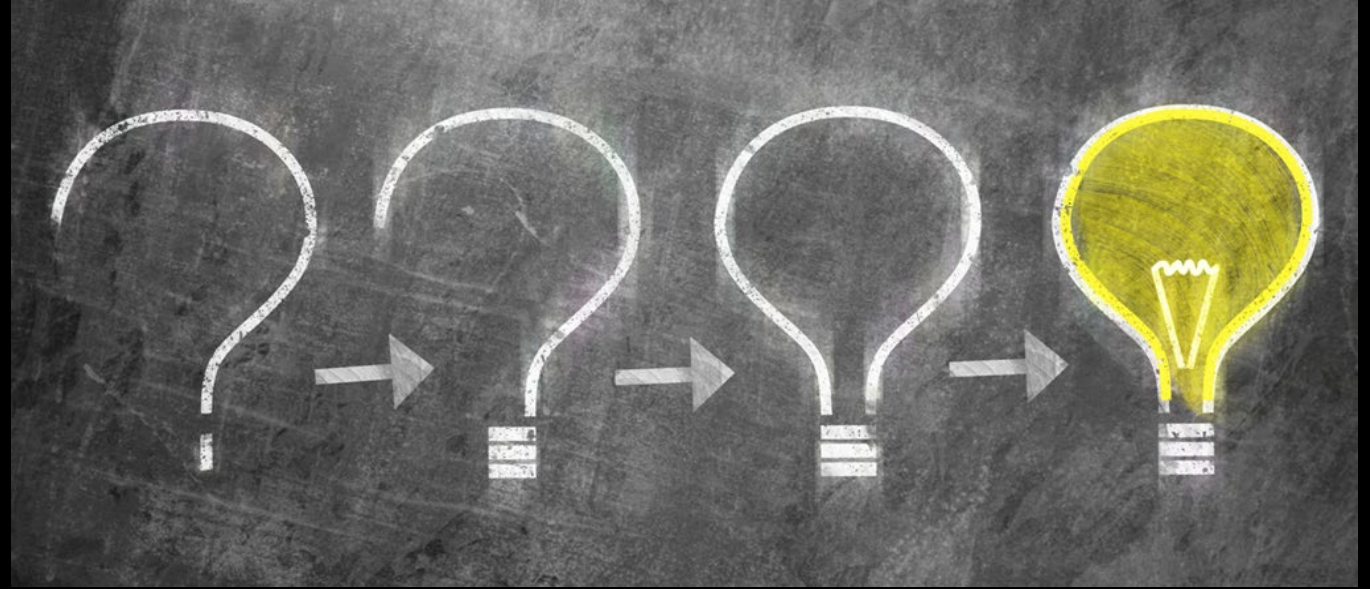
Being in heavy traffic or living near a road with heavy traffic may be risky compared with being in other places in a community. Growing evidence shows that many different pollutants along busy highways may be higher than in the community as a whole, increasing the risk of harm to people who live or work near or use busy roads.

The number of people living "next to a busy road" may include 30 to 45 percent of the urban population in North America. The area most affected, they concluded, was roughly the band within 0.2 to 0.3 miles (300 to 500 meters) of the highway.

## References:

1. Health Effects Institute Panel on the Health Effects of Traffic-Related Air Pollution, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects*. Health Effects Institute: Boston, 2010. Available at [www.healtheffects.org](http://www.healtheffects.org).
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3. Finkelstein MM, Jerrett M., Sears M.R. Traffic Air Pollution and Mortality Rate Advancement Periods. *Am J Epidemiol*. 2004; 160: 173-177; Hoek G, Brunekreef B, Goldbohn S, Fischer P, van den Brandt. Associations between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet*. 2002; 360: 1203-1209.
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5. Suglia SF, Gryparis A, Schwartz J, and Wright RJ. Association between Traffic-Related Black Carbon Exposure and Lung Function among Urban Women. *Environ Health Perspect*. 2008;116 (10): 1333-1337.
6. Chen H, KJC, Capes R, et al. Living near major roads and the incidence of dementia, Parkinson's disease and multiple sclerosis: a population-based cohort study. *Lancet*. 2017. Published online [http://dx.doi.org/10.1016/5014-6736\(16\)32596-X](http://dx.doi.org/10.1016/5014-6736(16)32596-X).
7. Power MC, Weisskopf MG, Alexeeff SE, et al.,. Traffic-related air pollution and cognitive function in a cohort of older men. *Environ Health Perspect* 2011;119:682–687. doi:10.1289/ehp.1002767

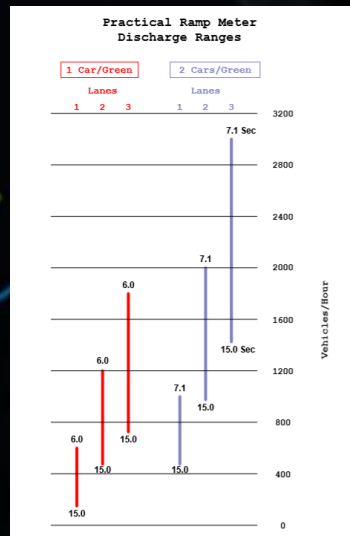
How can Caltrans reduce the impact of the extra Traffic Generated CO2 on Global Warming and to Public Health while simultaneously improve the traffic ?



By implementing a Goal Oriented Ramp Metering algorithm

# What is The current method of ramp metering?

The Current method of ramp metering when not in fixed rate mode (due to construction or detection malfunction) , is traffic responsive **meaning that the discharge from the ramp is a proportional response to measured state of the system.** The discharge cycles are tabulated between the maximum and minimum allowable cycles lengths with a **constant increment** to achieve the 15 discharge cycles used by the controller.

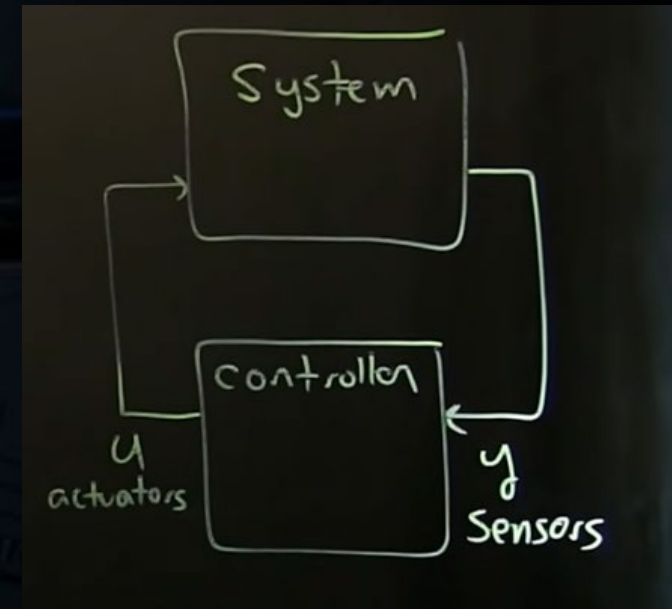


RATE TABLE			Discharge Rate	
RATE CODE	CYC/MIN	SEC/CYC	Veh/hr/Lane	veh/30sec
1	8.4	7.1	1008	8.4
2	8.09	7.4	971	8.09
3	7.78	7.7	934	7.78
4	7.47	8.0	896	7.47
5	7.16	8.4	859	7.16
6	6.85	8.8	822	6.85
7	6.54	9.2	785	6.54
8	6.23	9.6	748	6.23
9	5.92	10.1	710	5.92
A	5.61	10.7	673	5.61
B	5.3	11.3	636	5.3
C	4.99	12.0	599	4.99
D	4.68	12.8	562	4.68
E	4.37	13.7	524	4.37
F	4.06	14.8	487	4.06

2 cars/green

RATE TABLE			Discharge Rate	
RATE CODE	CYC/MIN	SEC/CYC	Veh/hr/Lane	veh/30sec
1	6	10.0	720	6
2	5.86	10.2	703	5.86
3	5.72	10.5	686	5.72
4	5.58	10.8	670	5.58
5	5.44	11.0	653	5.44
6	5.3	11.3	636	5.3
7	5.16	11.6	619	5.16
8	5.02	12.0	602	5.02
9	4.88	12.3	586	4.88
A	4.74	12.7	569	4.74
B	4.6	13.0	552	4.6
C	4.46	13.5	535	4.46
D	4.32	13.9	518	4.32
E	4.18	14.4	502	4.18
F	4.04	14.9	485	4.04

1 car/green



The result of the current method of ramp metering



# Performance of Route I-5 in San Diego under current method of Ramp Metering

Practical Discharge rates standard and Current Performance of State Route I -5 in San Diego



# What is Model Predictive Control ?

**Model predictive control (MPC)** is a control scheme where a model is used for predicting the future behavior of the system over finite time window.

Based on these predictions and the current measured state of the system, the optimal control inputs with respect to a defined **control objective** is computed.

Since the traffic model is non-linear, the model equation needs to be solved numerically to achieve the **control objective** .

A common mathematical method of solving a nonlinear equation is particle filtering , wherein a group of test numbers (discharge rates) are tried in the model and the output of the model is measured against the **control objective** . The difference is then minimized to improve on the selection of another set of discharge rates that results in an output for the model as close as possible to the **control objective** .

# The Analytic Non Linear Model

The density evolution model will follow the transformation of upstream values to downstream via a simple equation

$$n_{ds}(T) = \frac{1}{V_{ups}(t)} \left( Q_{ups}(t) + \frac{q_{ramp}(t)}{\aleph} \right) - \frac{1}{\aleph} \frac{q_{exit}(T)}{V_{merge}}$$

Where  $V_{merge}$  is given by

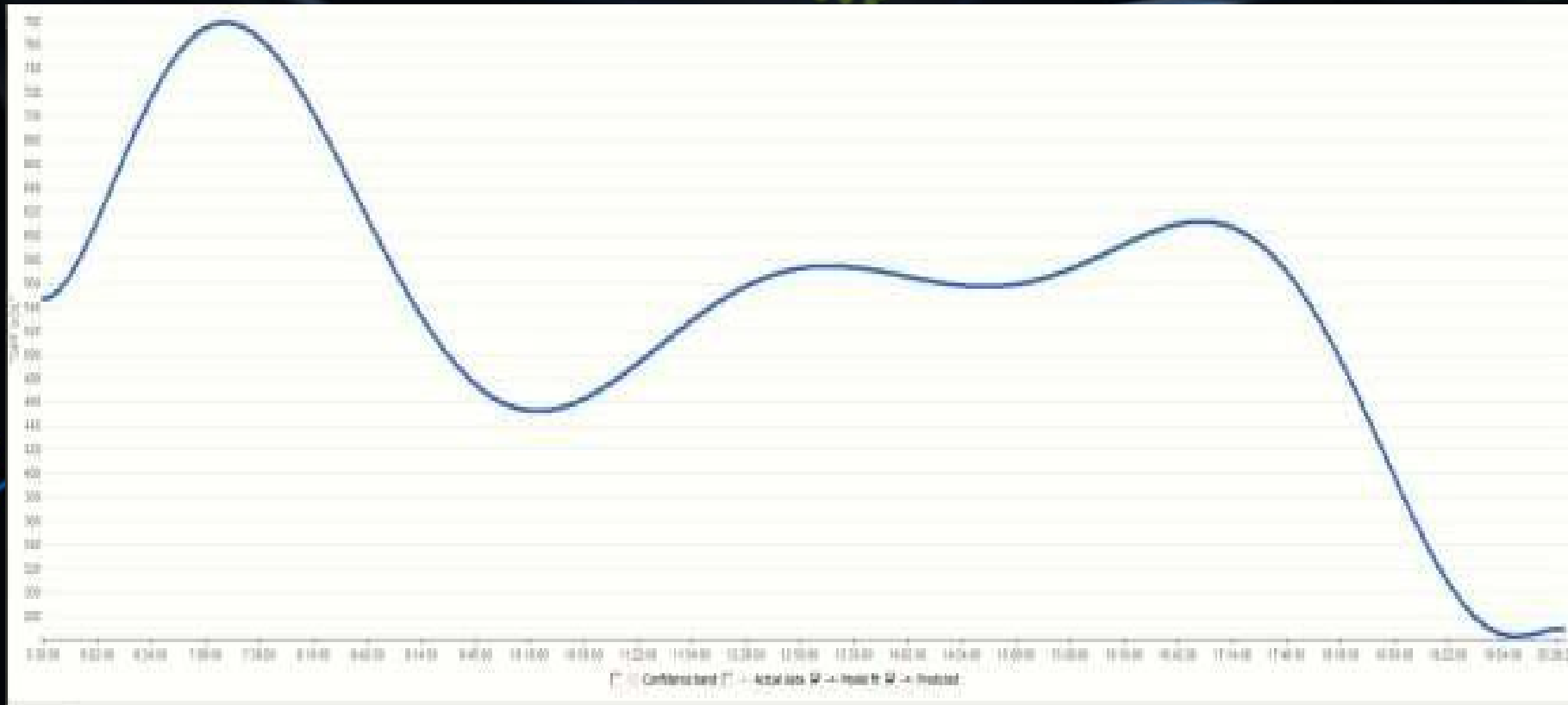
$$T = \frac{\Delta x}{V_{merge}}$$

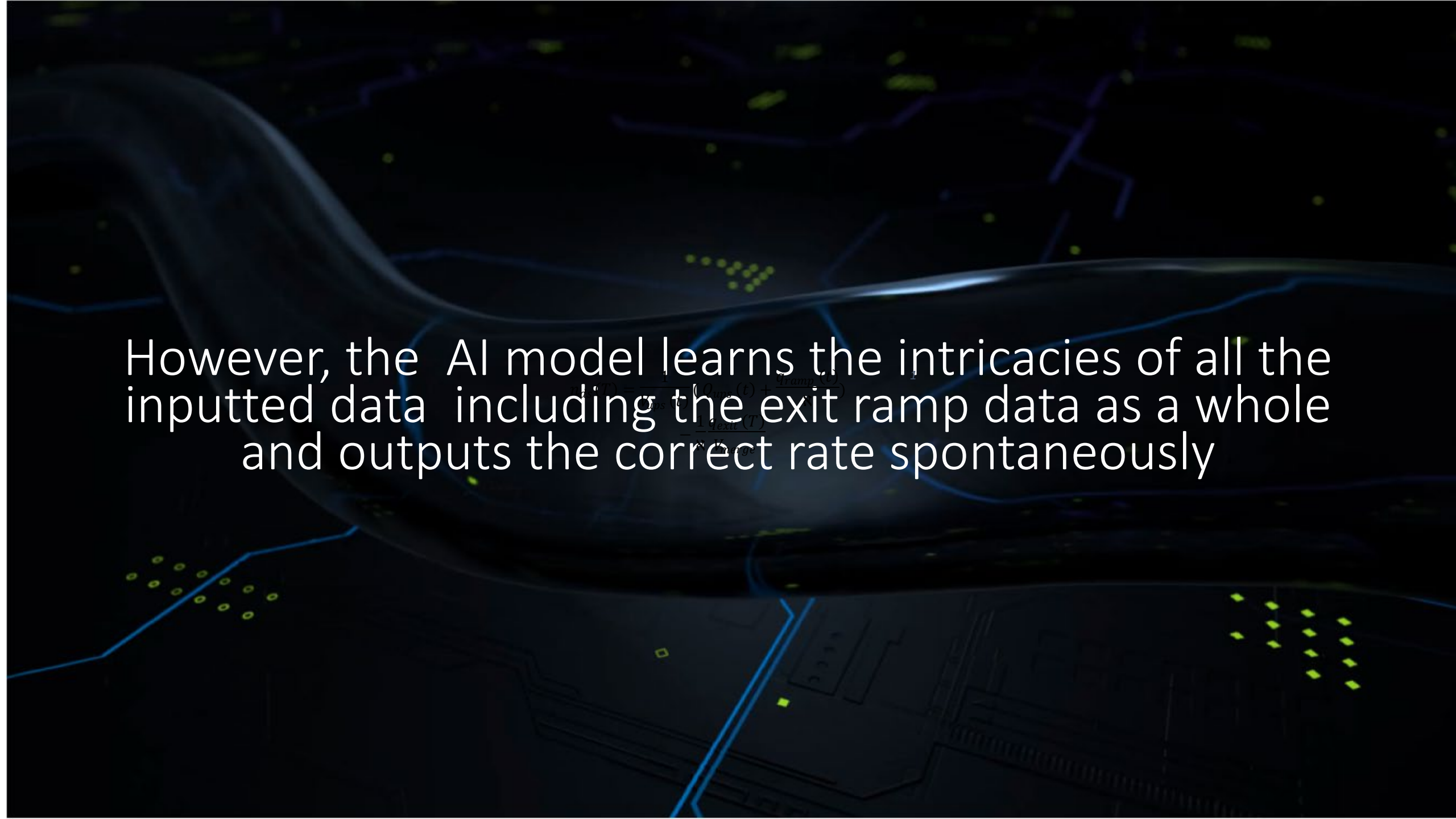
$$V_{merge} = \min \left\{ V_{ups}(t), \frac{5280 \aleph V_{ups}(t)}{\tau \underline{c} (\aleph Q_{ups}(t) + q_{ramp}(t))} - \frac{L}{\tau \underline{c}} \right\}$$

where  $\tau$  is the minimum headway at 1.75 sec and  $L$  is a typical car length at 14.75 ft, 5280 is the number of feet in one mile and  $\underline{c}$  is conversion from ft/sec to MPH.

# The Disadvantage of an analytic model

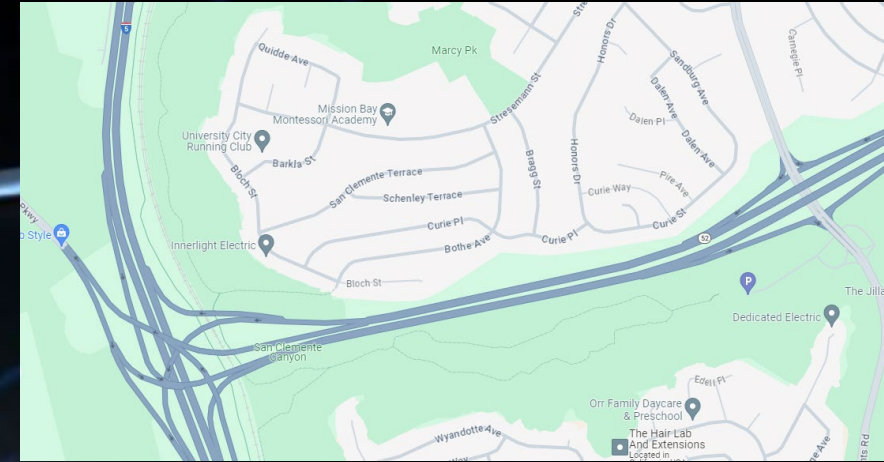
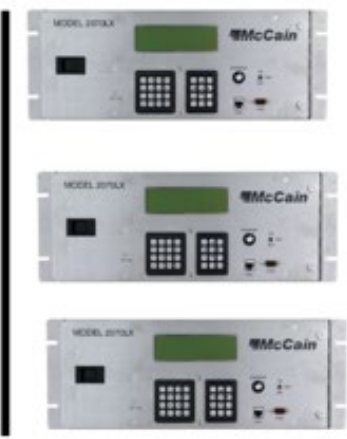
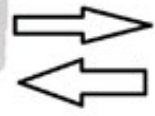
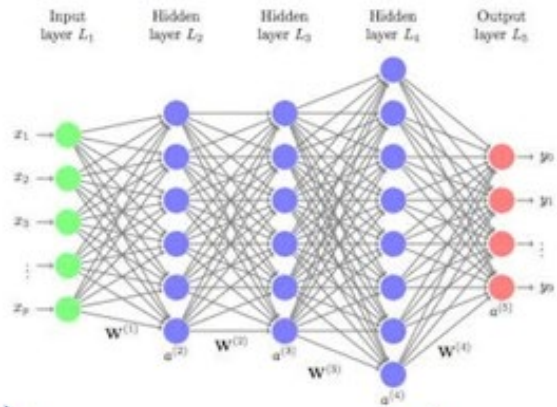
The analytic model relies on curve fitting method to predict the future q exit (T) rate at the down stream ramp



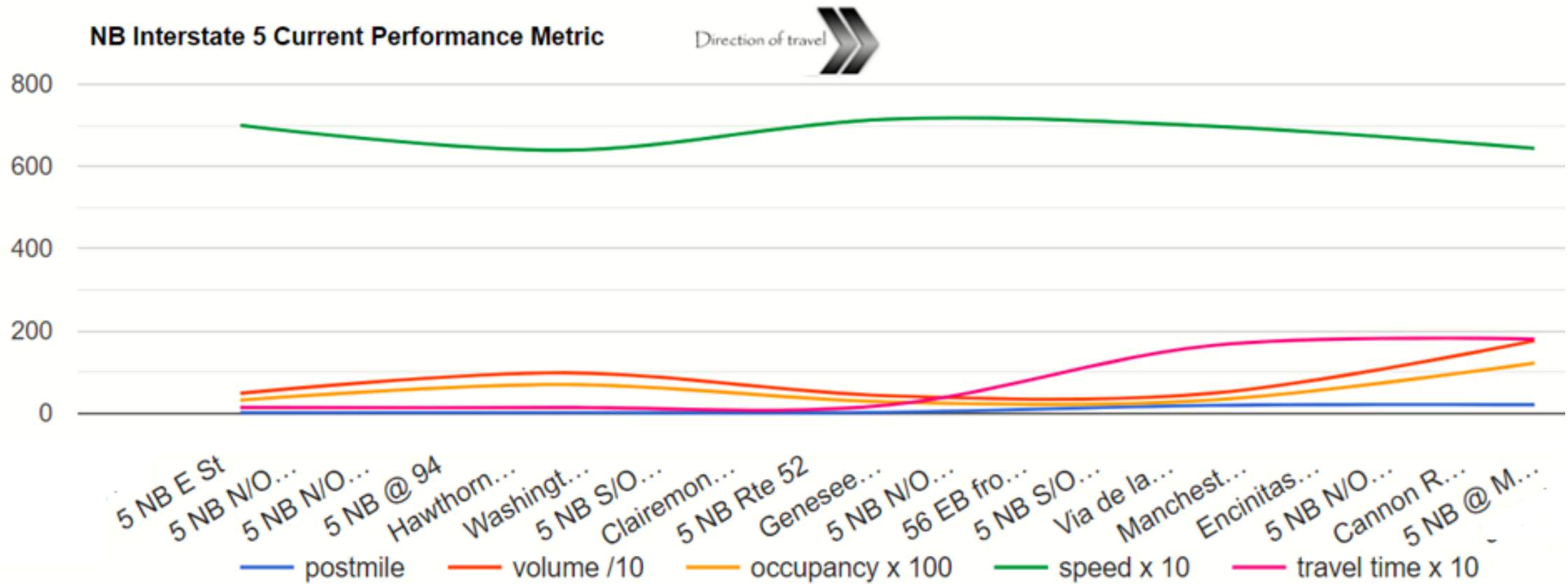
The background is a dark, abstract digital space. It features glowing blue lines that curve and flow across the frame, resembling data paths or neural network connections. Interspersed among these lines are clusters of small, bright green dots, some arranged in patterns that suggest data points or nodes. The overall aesthetic is futuristic and technological.

However, the AI model learns the intricacies of all the inputted data including the exit ramp data as a whole and outputs the correct rate spontaneously

# The envisioned AI operated Ramp metering system



# Expected Performance of State Route I-5 in San Diego under AI ramp Metering





- References:

- <https://news.berkeley.edu/2022/08/04/a-simple-cheap-material-for-carbon-capture-perhaps-from-tailpipes>

- [PeMS study by University of San Diego](#)

- [https://www.academia.edu/72016979/Corridor\\_Ramp\\_Metering\\_Using\\_Particle\\_Filter\\_Model\\_predictive\\_Control\\_PF\\_MPC\\_V](https://www.academia.edu/72016979/Corridor_Ramp_Metering_Using_Particle_Filter_Model_predictive_Control_PF_MPC_V)