Ramp Metering for Minimization of Traffic Emissions

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Introduction

If you have ever driven in California, then you most likely have experienced stop-and-go traffic. This frequently experienced phenomenon is characterized by traffic patterns that abruptly change from free-flow to nearly stopped vehicles. Prolonged commute can result in increased emissions from traveling vehicles. Our research focuses on incorporating a microscopic emissions model with a macroscopic traffic model to examine the impact of emissions and fuel consumption through various traffic patterns. Secondly, come up with a ramp metering algorithm with the goal of minimizing traffic emissions.

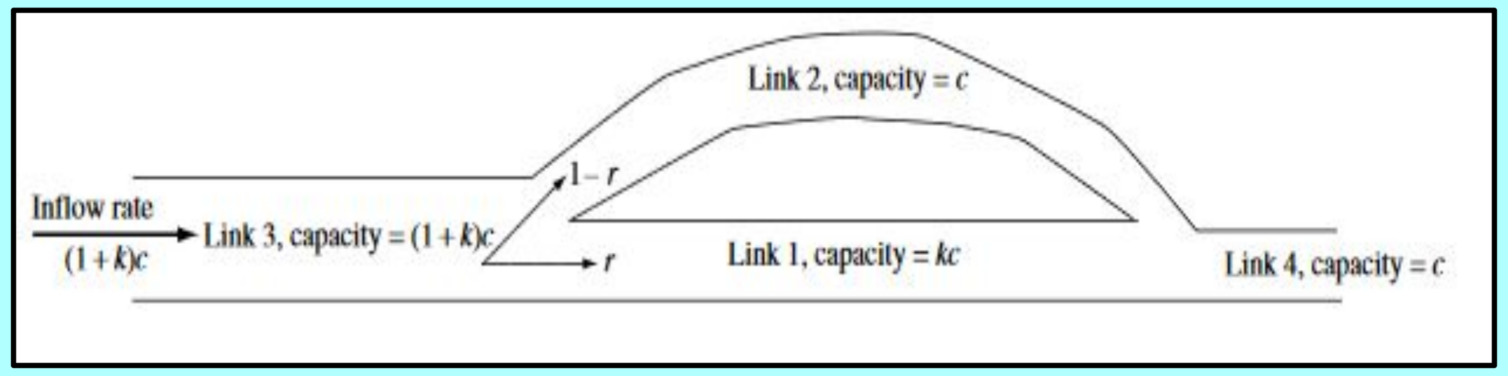

Figure 1: A homogenous road network with merge and diverge [1].

Background

We use the Lighthill, Whitham, and Richards (LWR) traffic flow model [1] to compute macroscopic characteristics of flow, density, and velocity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(f(\rho)) = 0$$

Here, f denotes average traffic flow and ρ denotes average traffic density.

This model is also called the hydrodynamic model because it describes the flow of traffic as being similar to the flow of water through a channel.

The emissions model we use is the VT-micro model [3], which computes emissions of CO, HC, NO_x and fuel consumption based on the microscopic traffic quantities of per-vehicle velocity and acceleration:

$$\overline{J}_{y,m,i}(k) = \Delta t\; n_{m,i}(k) \exp(\tilde{v}^T_{m,i}(k)\; P_y\; \tilde{a}^T_{m,i}(k))$$

- $\overline{J}$ is the aggregate emissions of type y
- Δt is the length of one time step
- v, a are the mean velocity, acceleration
- P is a parameter matrix specific to emission type y
- m, i are spatial variables
- k is the time step counter

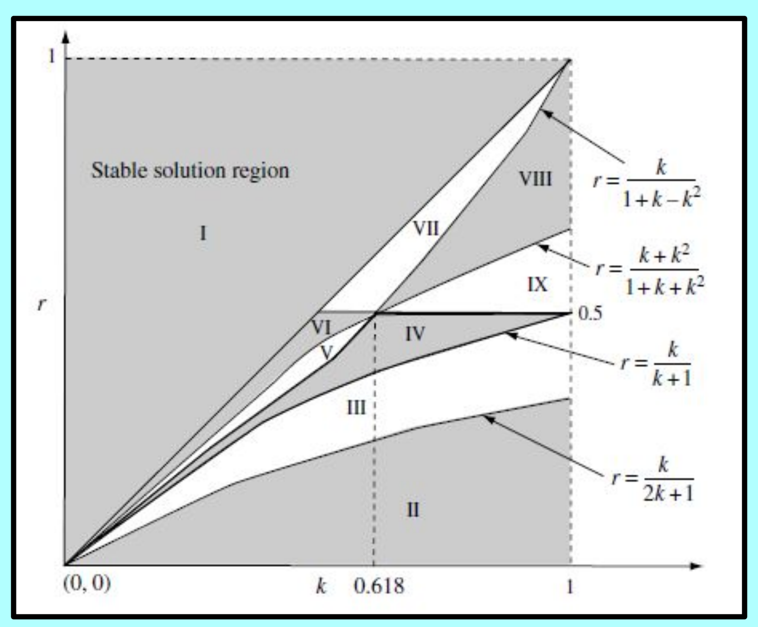

Figure 2: Relationship between ramp metering rate (r) and capacity ratio (k) [1]. Each subspace represents a specific traffic pattern.

Methods and Results

Using Mathematica, we implemented the LWR model [1] of traffic flow and integrated these results with the VT-Micro emissions model [3]. We then are able to compute the average emissions for a single strip of road over time.

Finally, we estimate the average emissions per vehicle for the total run-time of the simulation.

The results show that the flow of traffic closely follows the emissions of the vehicles.

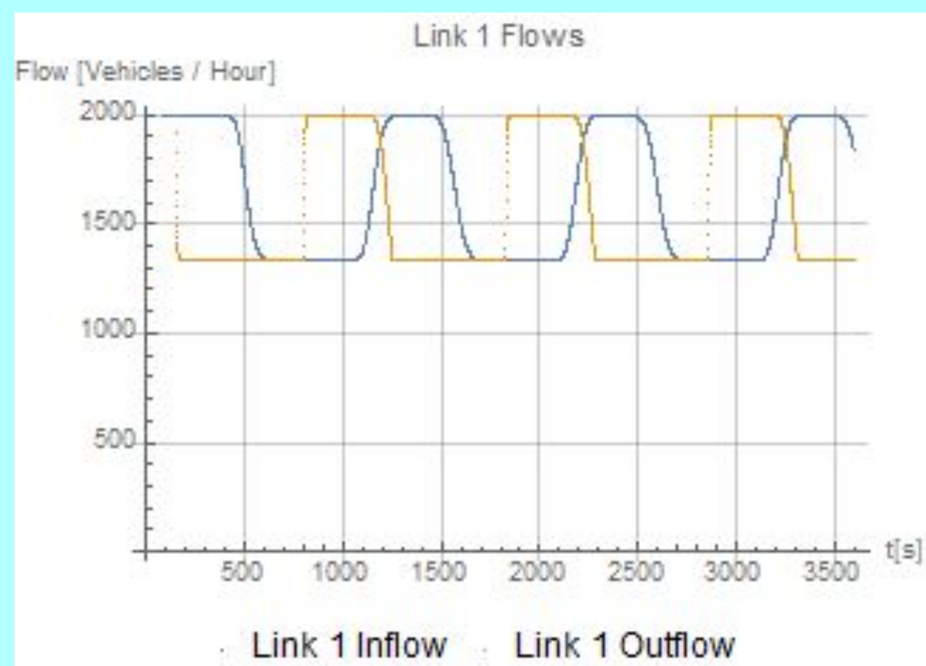

Figure 3: Inflows/Outflows for Link 1, r = 0.4, k = 0.5

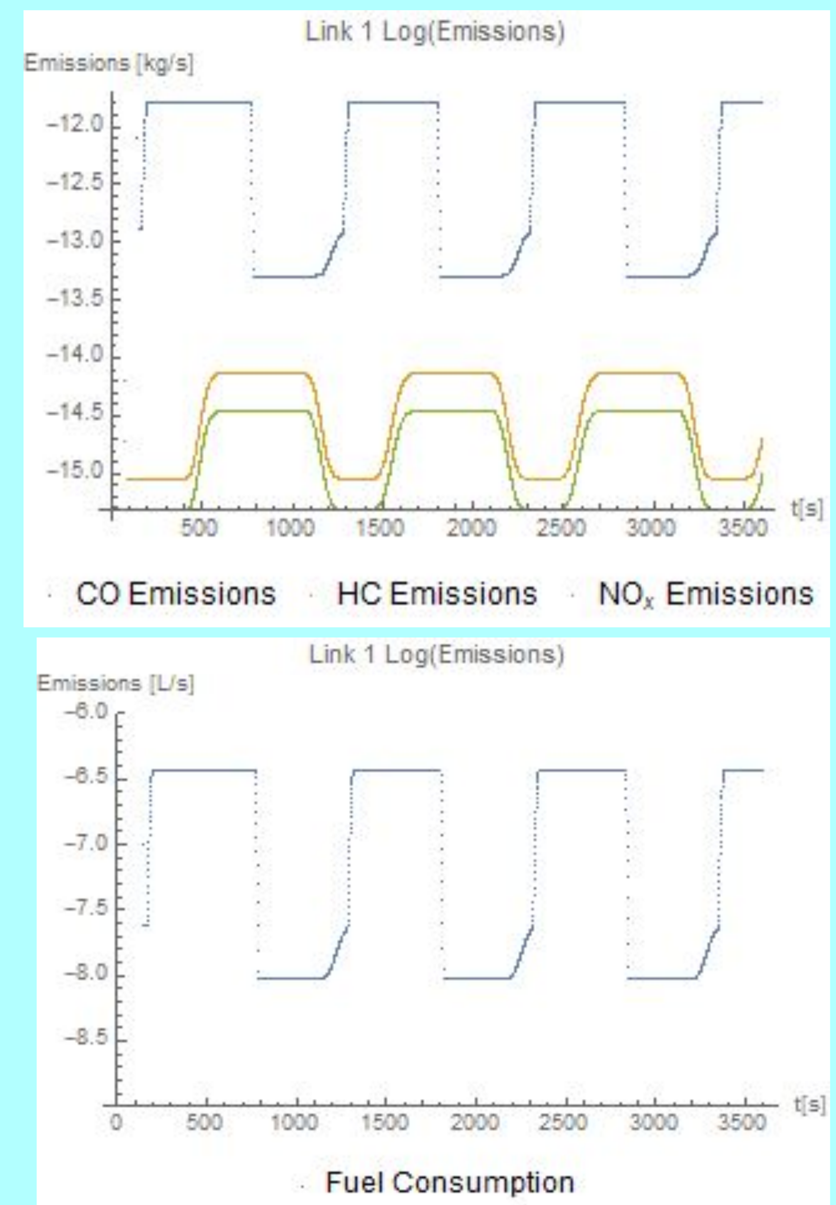

Figure 4: Emissions (above) and Consumption (below) data for Link 1 in the case r = 0.4, k 0.5

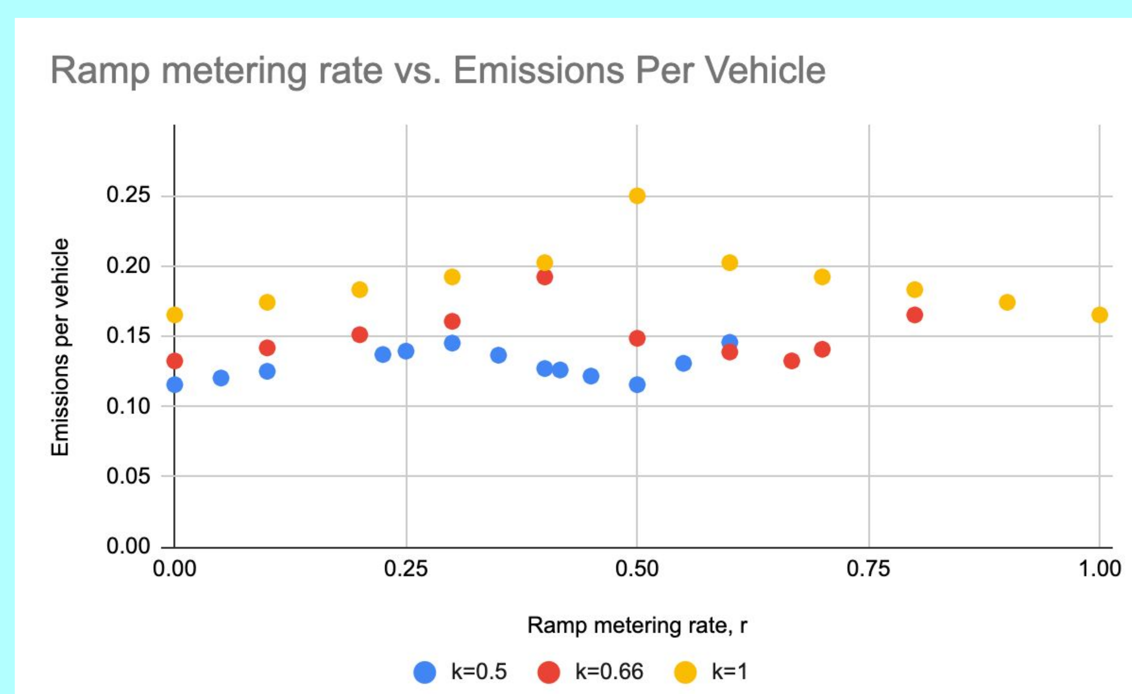

Figure 5: The initial data indicate that emissions per vehicle are minimized either when flow from the on-ramp is zero (r=0) or when the proportion of traffic on the on-ramp is proportional to its capacity (r=k).

Discussion and Future Research

Our results reveal that flow dictates emission rates, and that flow is dictated by the relationship of r (metering rate) to k (network volume ratio).

Figure 5 shows that the average emissions per vehicle is maximized in the region between periodic and decaying stop-and-go traffic, with the emissions minimized at **r =0** and **r = k**.

For **r = 0**, we suspect that queueing at the Link 3 diverge limits the total number of cars that can enter the system, thus minimizing congestion.

For **r = k**, Link 1 is being fully utilized while Link 2 takes the majority of the traffic in the system.

Thus, ramp meters should be timed so that the proportion of traffic entering the freeway is as close as possible to the capacity ratio of the merge lane to the mainline for minimizing emissions.

Some future directions for the project are:

- Improve metrics for determining emissions
- Implement time-varying metering rate (r), which allows for better control
- Alter the road configuration means more control points (e.g., add an on-ramp)

References

[1] Lighthill, M. J., and G. B. Whitham. "On Kinematic Waves ." *Proceedings of the Royal Society*, 10 May 1955, royalsocietypublishing.org/doi/abs/10.1098/rspa.1955.0088.

[2] Nie (Marco), Yu, and H. Michael Zhang. "Oscillatory Traffic Flow Patterns Induced by Queue Spillback in a Simple Road Network." *Transportation Science*, vol. 42, no. 2, 2008, pp. 236–248., doi:10.1287/trsc.1070.0229.

[3] Zegeye, S. K., De Schutter, B., Hellendoorn, J., Breunesse, E. A., & Hegyi, A. (2013). Integrated macroscopic traffic flow, emission, and fuel consumption model for control purposes. *Transportation Research Part C: Emerging Technologies*, *31*, 158-171.

Acknowledgements

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