Modeling Traffic Emissions in Networks with Macroscopic Traffic Models

Advancing Metropolitan Modeling for the Analysis of Urban Sustainability Policies
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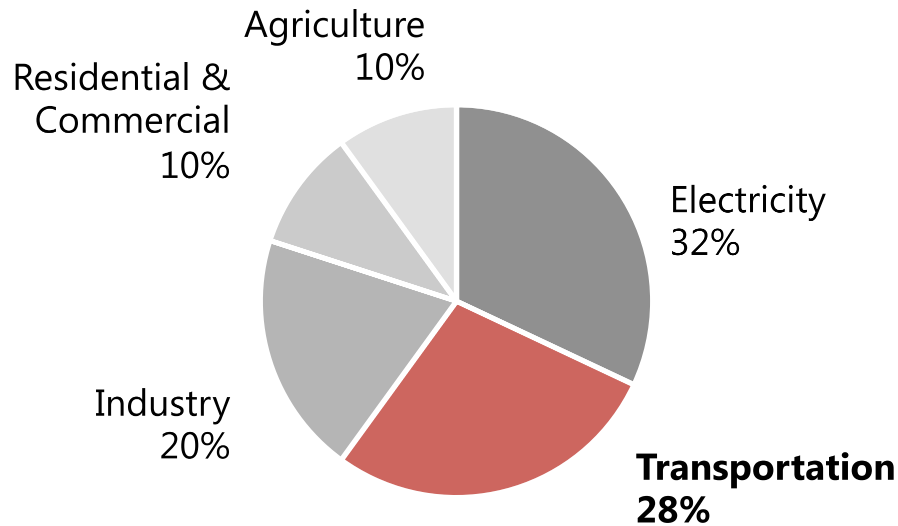
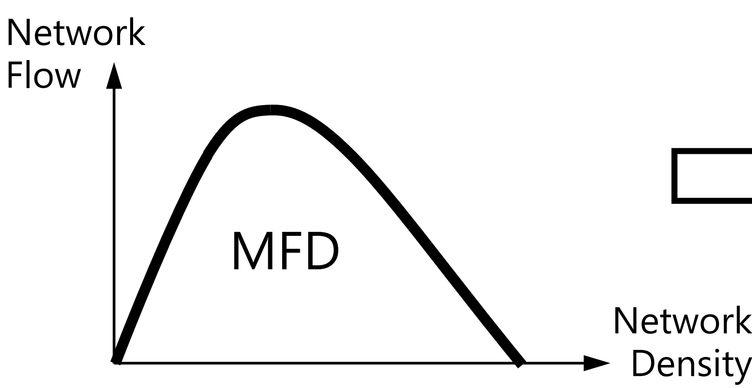
Problem of Interest

Traffic is a major source of greenhouse gas emissions (CO_2 equivalent).



(USEPA, 2013)

How can macroscopic traffic models be used for making aggregated emissions estimates?



Modeling Traffic and Emissions

	Traffic	Emissions
Microscopic	Detailed movements of individual vehicles (includes micro-simulation)	Detailed emissions estimates based on second-by-second speeds; requires extensive data
Mesoscopic	Traffic streams, accounting for some characteristics (such as heterogeneous driver behavior)	Driving cycles estimated from aggregated inputs; requires speeds and number of stops
Macroscopic	Aggregated network-wide traffic conditions; useful for analysis of large networks	Direct estimation of aggregated emissions; not sensitive to changes in driving cycles

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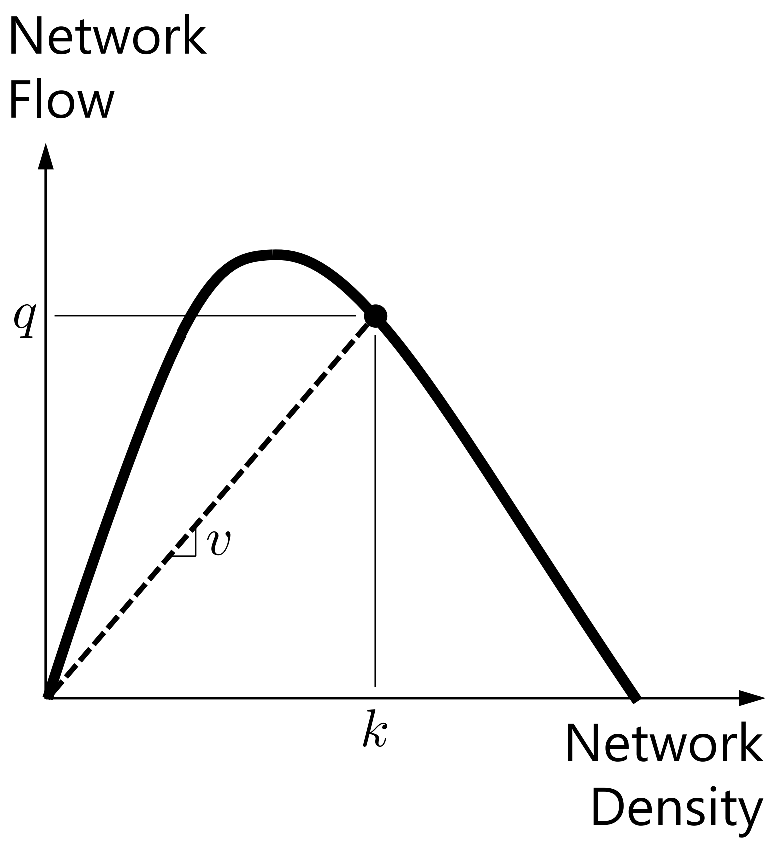
Macroscopic Traffic Model

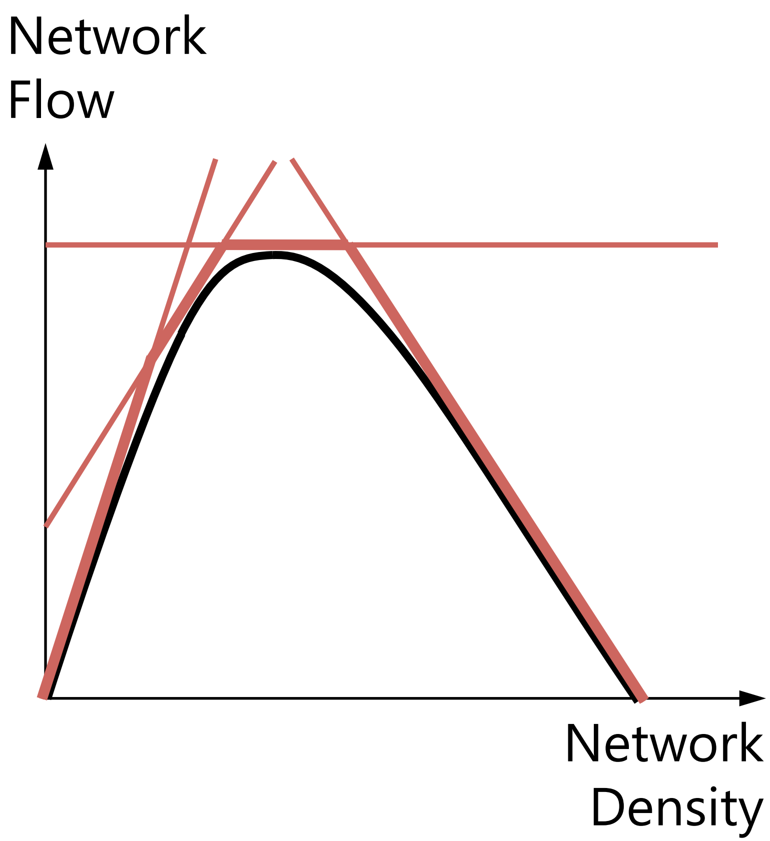


Macroscopic Fundamental Diagram (MFD) relates flow and density for a network based on the properties of the network and traffic.

(Daganzo and Geroliminis, 2008)

- Free flow speed
- Saturation Flow
- Jam Density
- Block Length
- Signal Timings

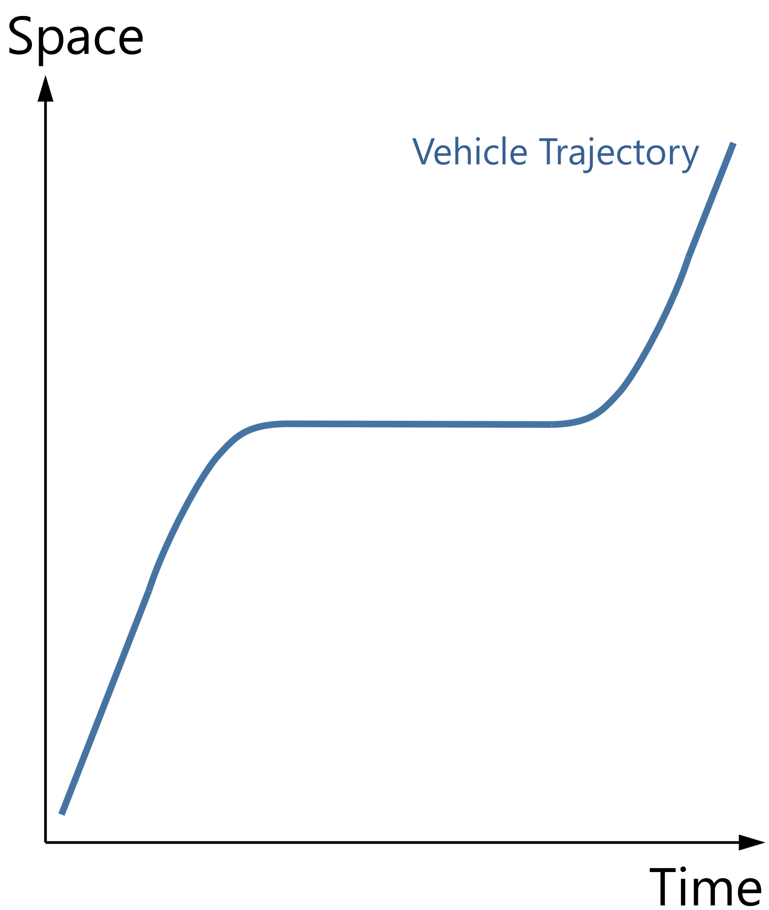
Macroscopic Traffic Model



The MFD can approximated analytically by identifying bounds of the feasible flows that can be achieved.

The analytical MFD is a tight bound for homogeneous networks with uniform distribution of traffic.
(Daganzo and Geroliminis, 2008)

Microscopic Emissions Models



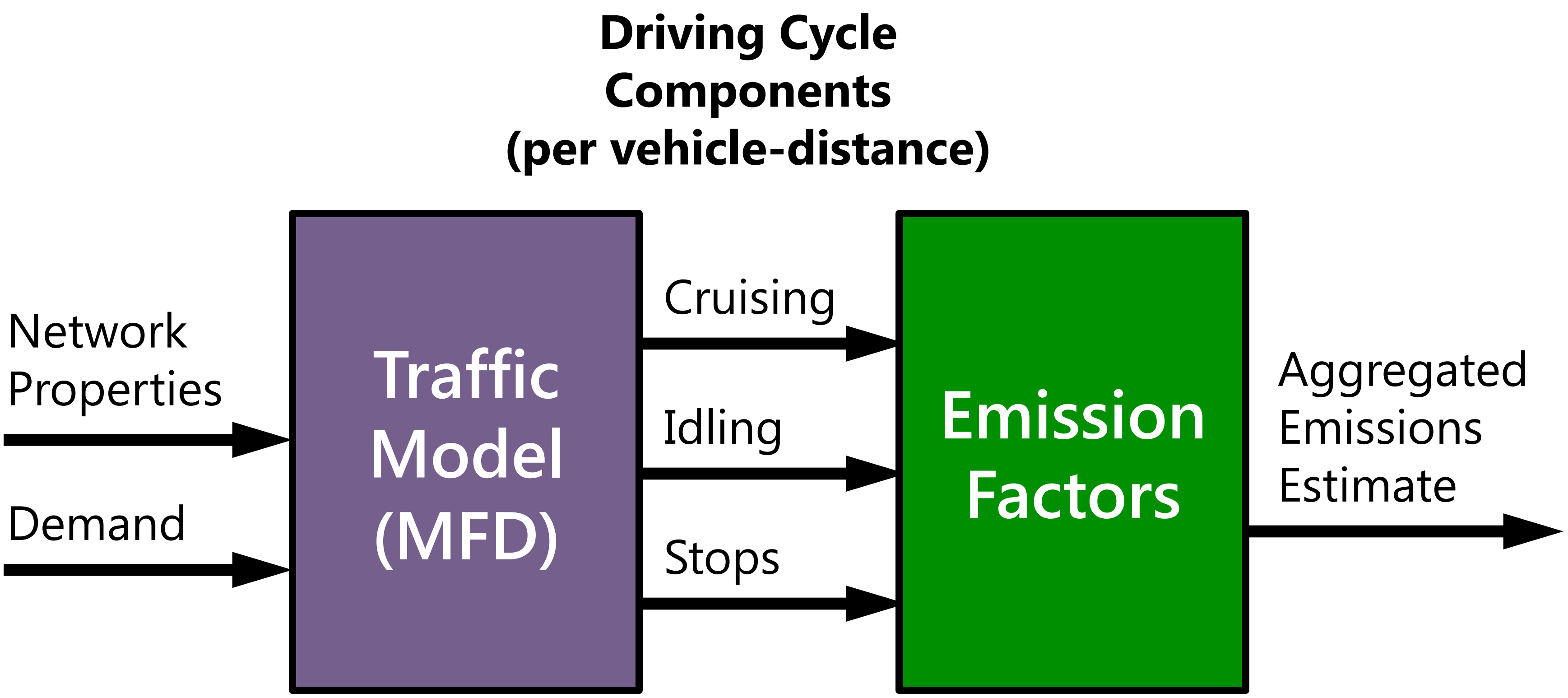
Second-by-second vehicle trajectory data

- Speed
- Acceleration

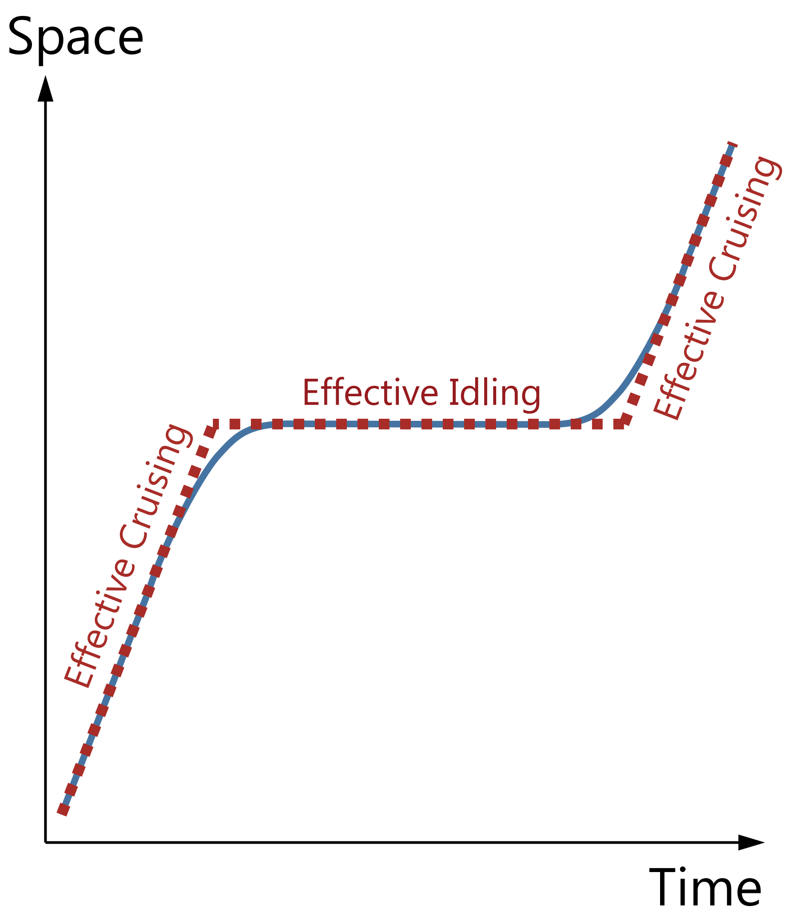
are inputs for microscopic emissions models

- VT-Micro (Rakha et al., 2000)
- CMEM (Barth et al., 2000)
- Project-level MOVES (USEPA, 2010)

Proposed Model Framework

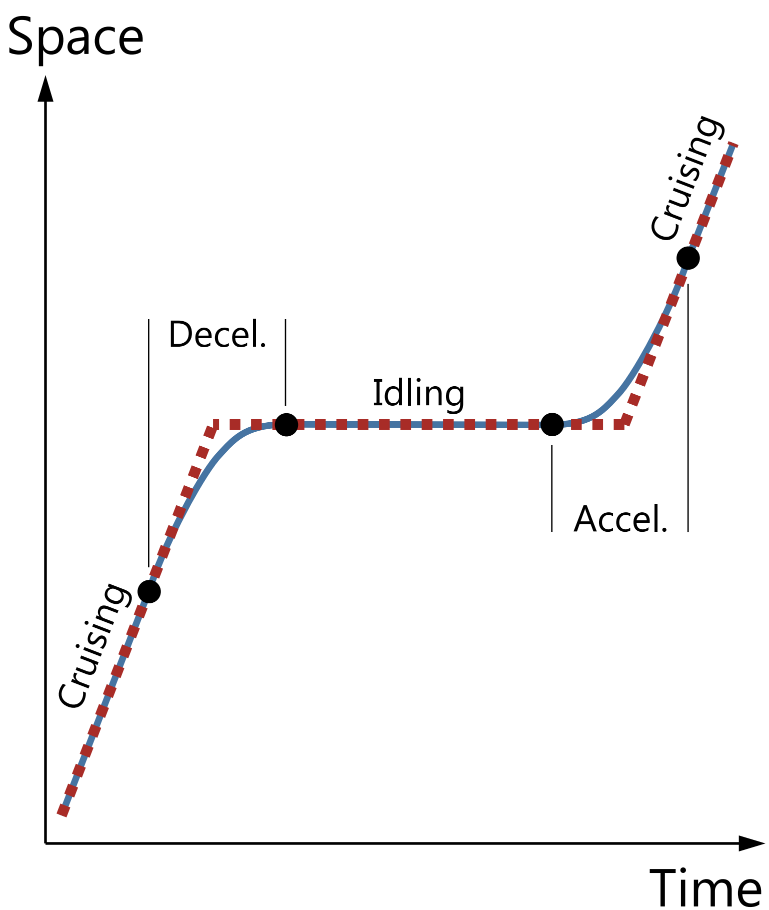


Driving Cycles and Traffic Flow Theory



Analytical models for trajectories with instantaneous acceleration are consistent with aggregate dynamics of real traffic streams.

Driving Cycles and Traffic Flow Theory



Analytical models for trajectories with instantaneous acceleration are consistent with aggregate dynamics of real traffic streams.

Trajectories can be broken into components of a driving cycle

- Cruising Time
- Idling Time
- Acceleration
- Deceleration

(Acceleration and Deceleration: Stopping)

Estimating Effective Cruising and Idling

We want to use the macroscopic traffic state to estimate components of the driving cycle.

Start by considering the implications for idealized trajectories with instantaneous acceleration and deceleration:

Effective Cruising Time $$\text{effective } T_c = \frac{1}{v_f}$$

Effective Idling Time $$\text{effective } T_i = \frac{1}{v} - \frac{1}{v_f}$$

v_f free flow speed

v network avg. speed

Estimating the Number of Stops

In a *homogeneous network* with *no signal offset*, suppose vehicles stop at least once per signal cycle (reasonable if red signal is longer than time to traverse one block).

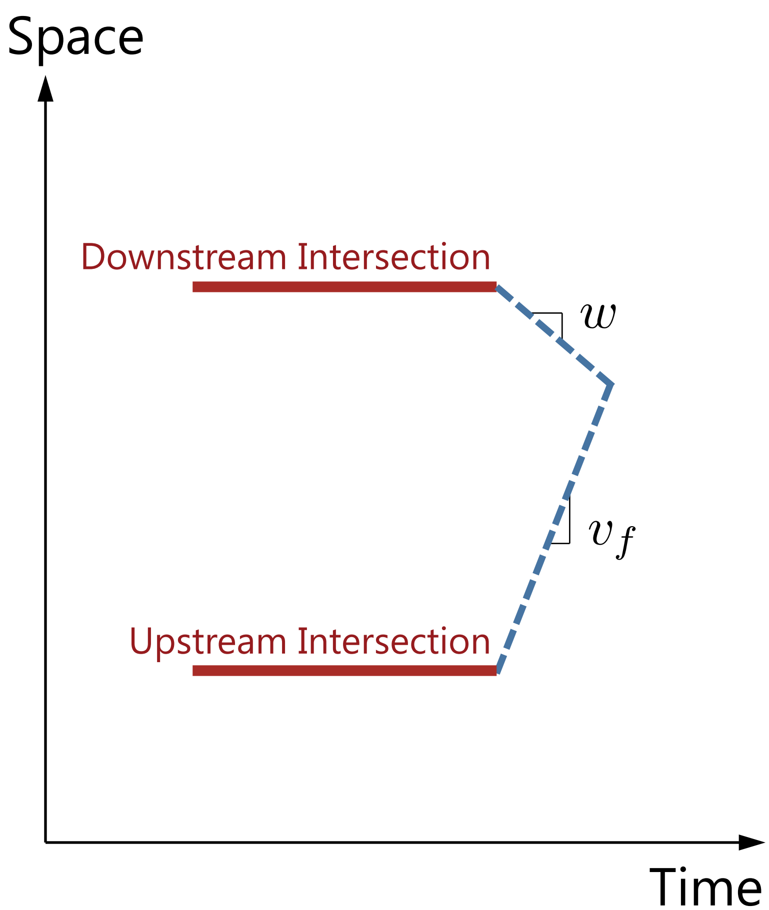
Vehicles have an extra stop if they are blocked by long queues at downstream intersections.

Number of Stops

$$n = \begin{cases} 1/vC & \text{if } k\left(w + v_f\right) \leq k_j w \\ 2/vC & \text{otherwise} \end{cases}$$

v	network avg. speed	k	vehicle density	v_f	free-flow speed
C	signal cycle length	k_j	jam density	w	backward wave speed

Estimating the Number of Stops



If the front of a platoon from an upstream intersection reaches the queue of the downstream intersection, every vehicle in the platoon stops an extra time.

Estimating the Driving Cycle

Actual time cruising and idling can be estimated by adjusting the effective time estimates are based on the average duration of acceleration and deceleration associated with each stop, τ.

Driving Cycle per Vehicle-Distance:

Cruising Time $$T_c = \frac{1}{v_f} - \frac{\tau}{2} n$$

Idling Time $$T_i = \frac{1}{v} - \frac{1}{v_f} - \frac{\tau}{2} n$$

Stops $$n = \begin{cases} 1/vC & \text{if } k\left(w + v_f\right) \leq k_j w \\ 2/vC & \text{otherwise} \end{cases}$$

Estimating Network-wide Emissions

Aggregated emissions are calculated by multiplying components of the driving cycle by corresponding emissions factors:

Emissions per Vehicle-Distance $E = e_c T_c + e_i T_i + e_s n$

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Emission factors depend on the free flow speed and average from a sample of accelerations and decelerations.

Using MOVES

$v_f = 53 \text{ km/hr}$

$\tau = 8.75 \text{ sec}$

(USEPA, 2010; Shabihkhani and Gonzales, 2013)

cruising	$e_c = 2.79 \text{ gCO}_2\text{eq/sec}$
idling	$e_i = 0.88 \text{ gCO}_2\text{eq/sec}$
vehicle stop	$e_s = 22.23 \text{ gCO}_2\text{eq/sec}$

Analytical Model vs. Simulation

Simulation is used for comparison with conventional, detailed, microscopic emission analysis.

$v_f = 53$ km/hr free-flow speed

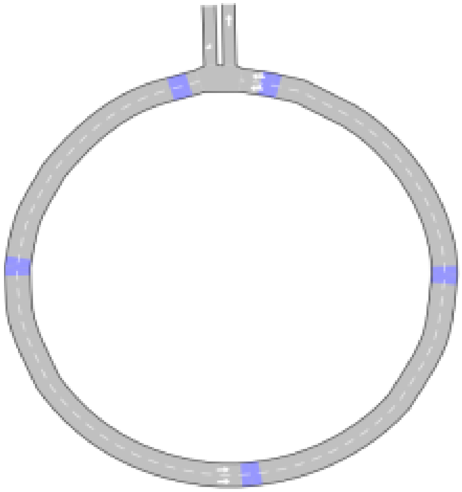
$s = 1900$ veh/lane-hr capacity

$k_j = 200$ veh/lane-km jam density

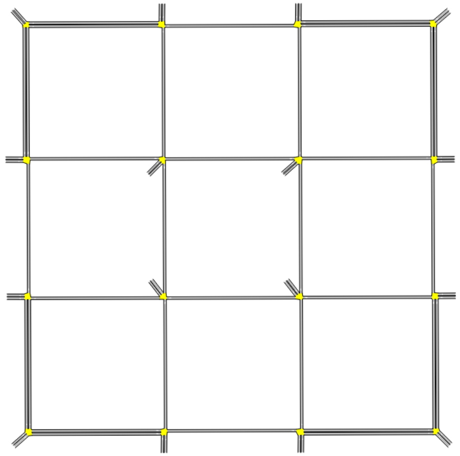
$G/C = 0.5$ green ratio

$C = 60$ sec signal cycle length

$\ell = 150$ m block length



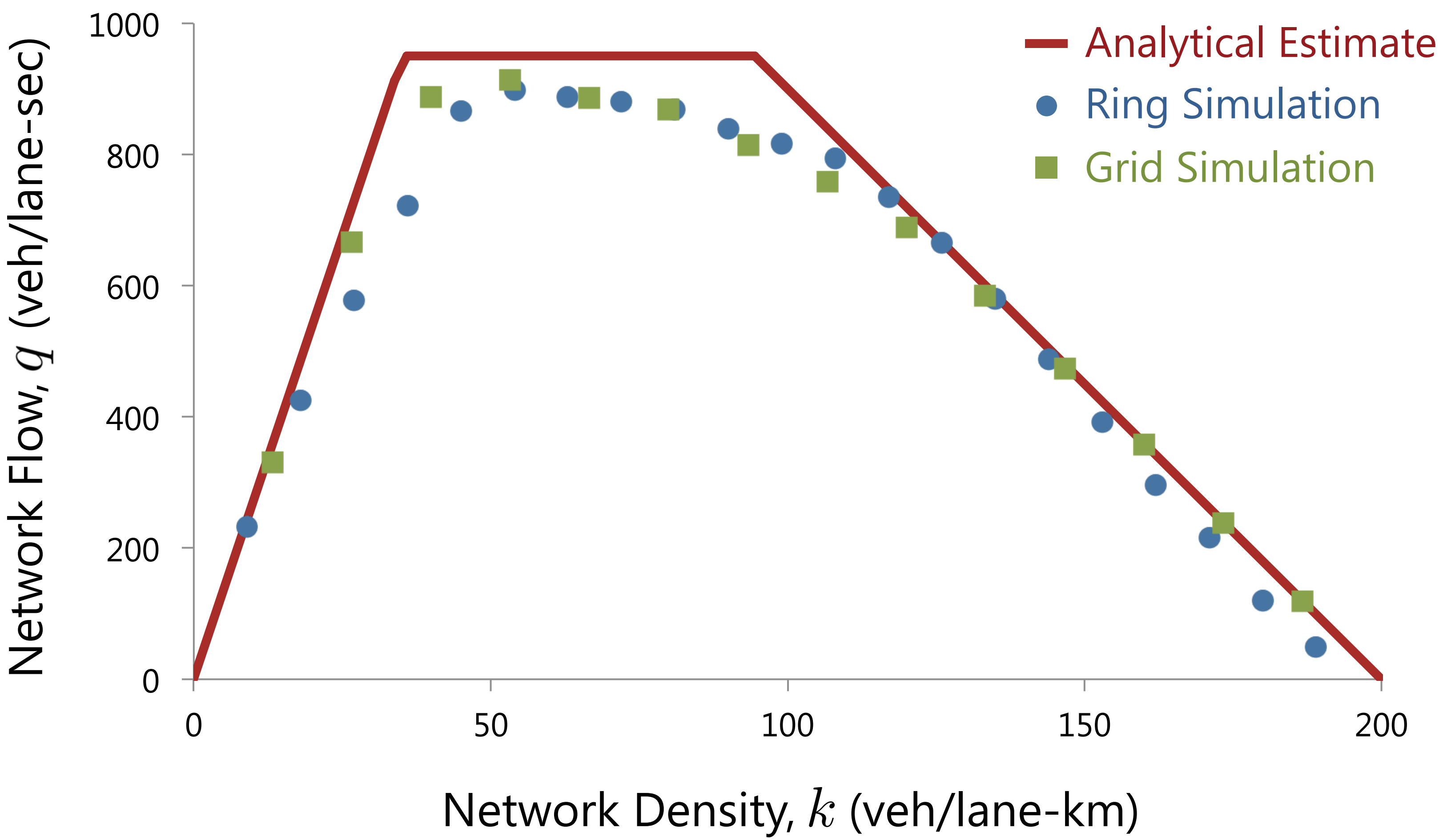
Ring Network



Grid Network

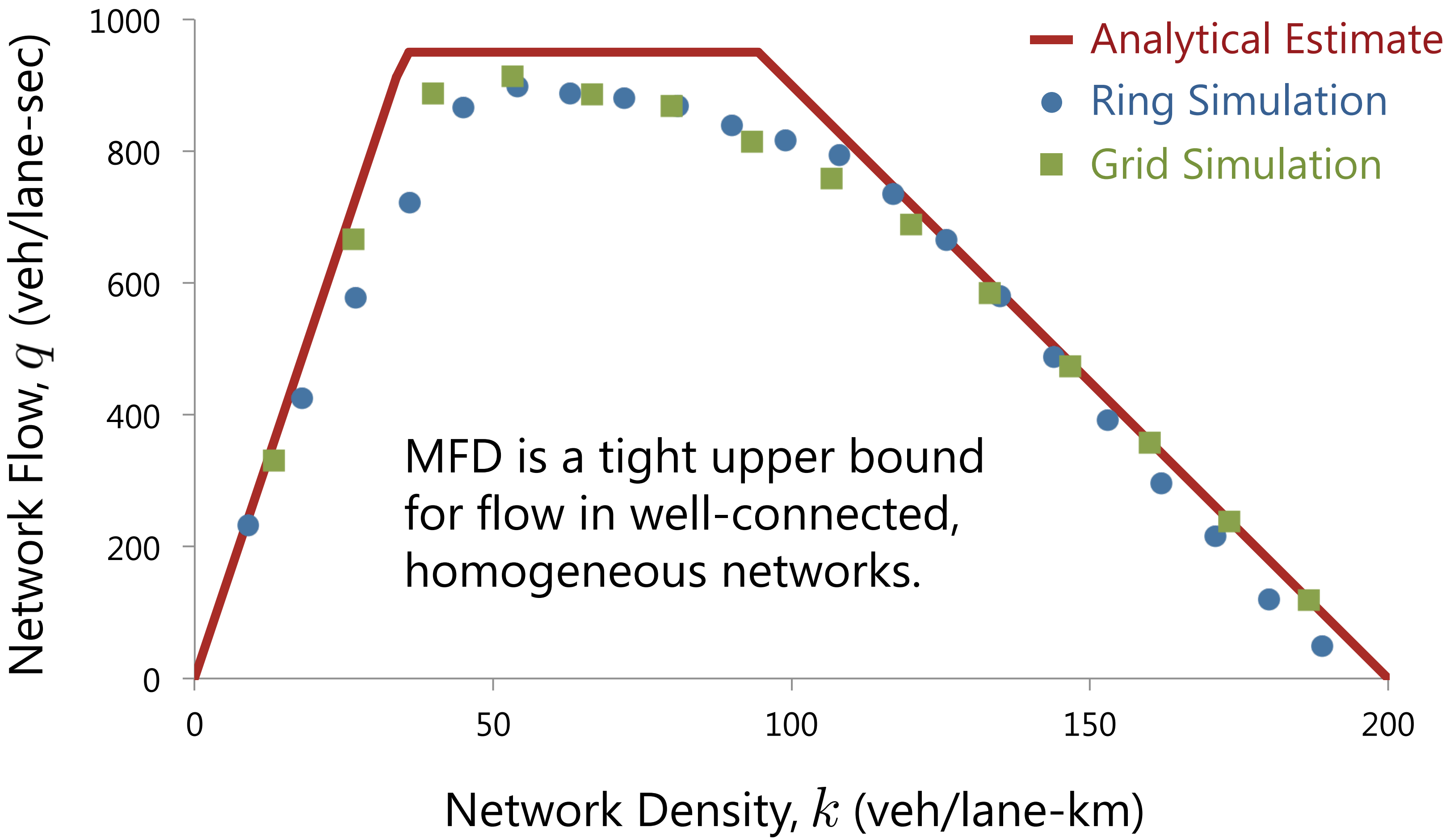
Analytical Model vs. Simulation

Network Flow



Analytical Model vs. Simulation

Network Flow



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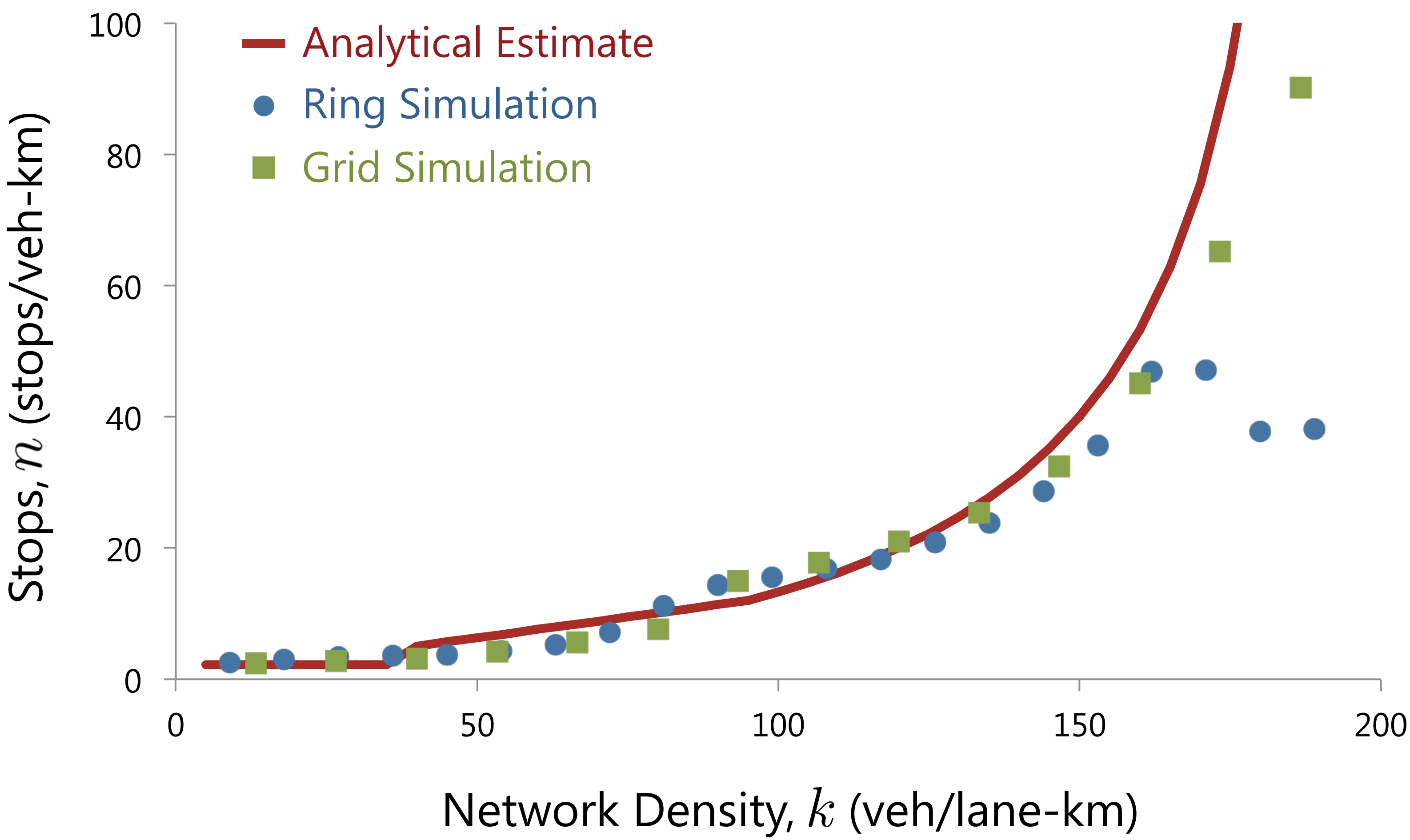
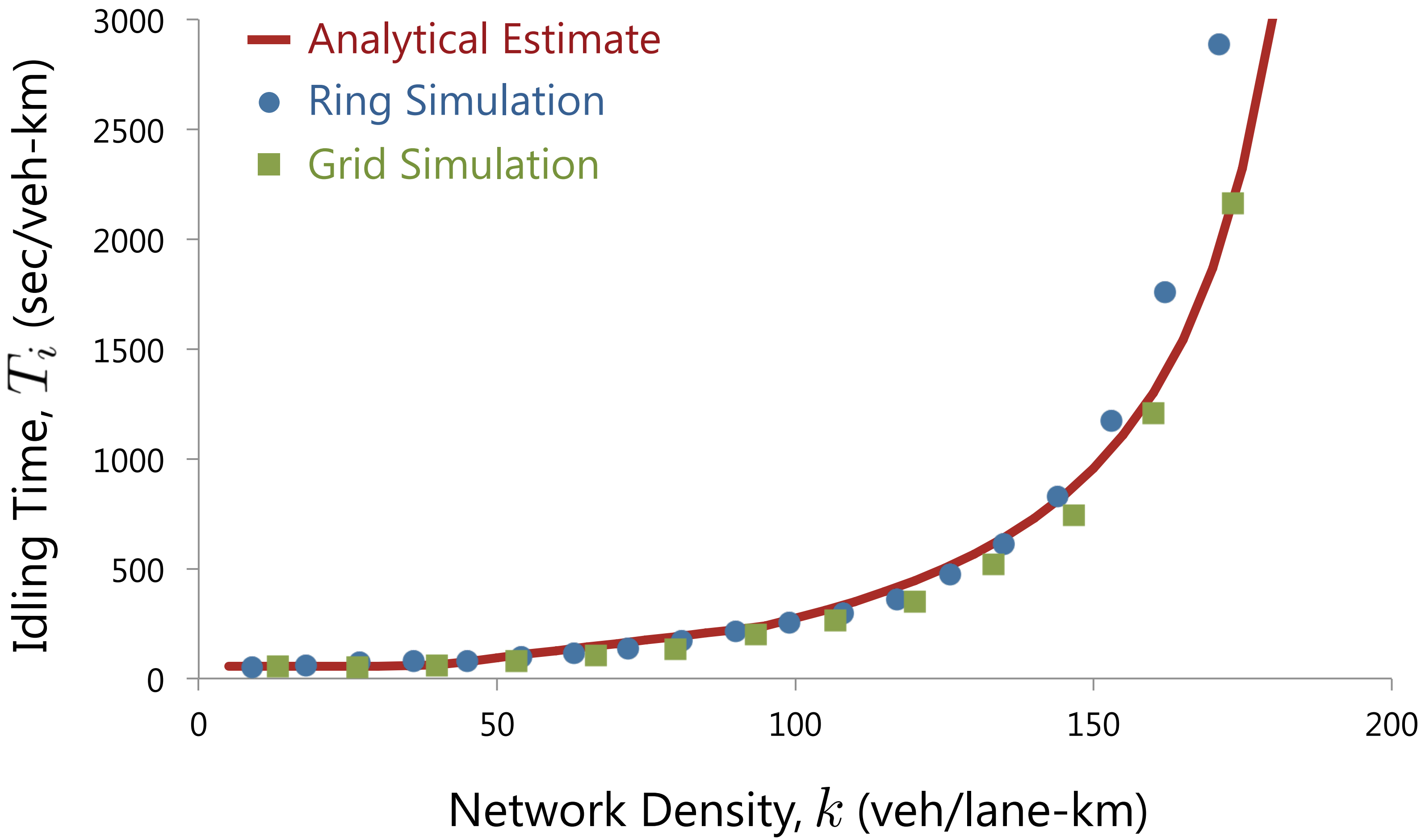


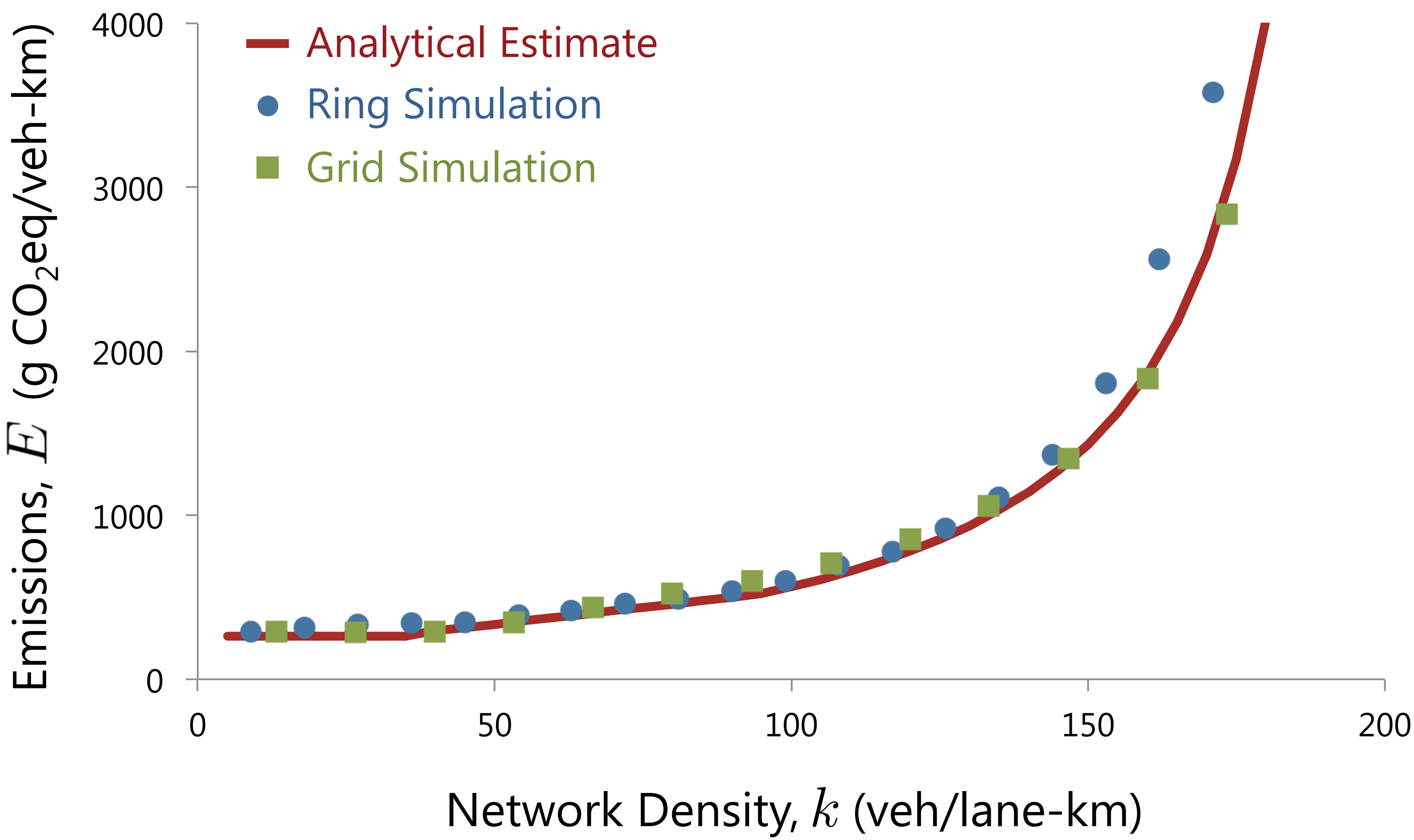
Analytical Model vs. Simulation

Idling Time



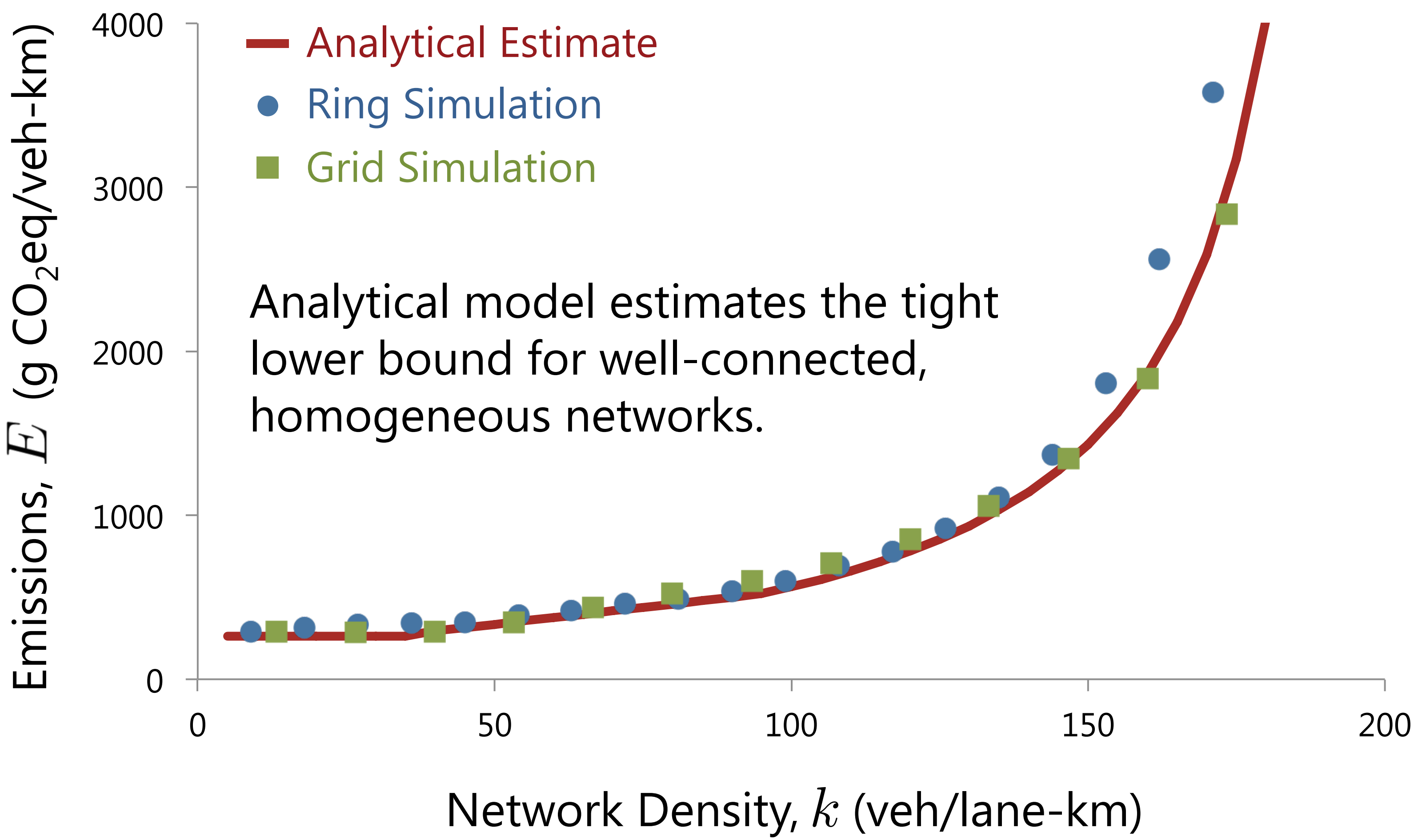
Analytical Model vs. Simulation

Greenhouse Gas Emissions



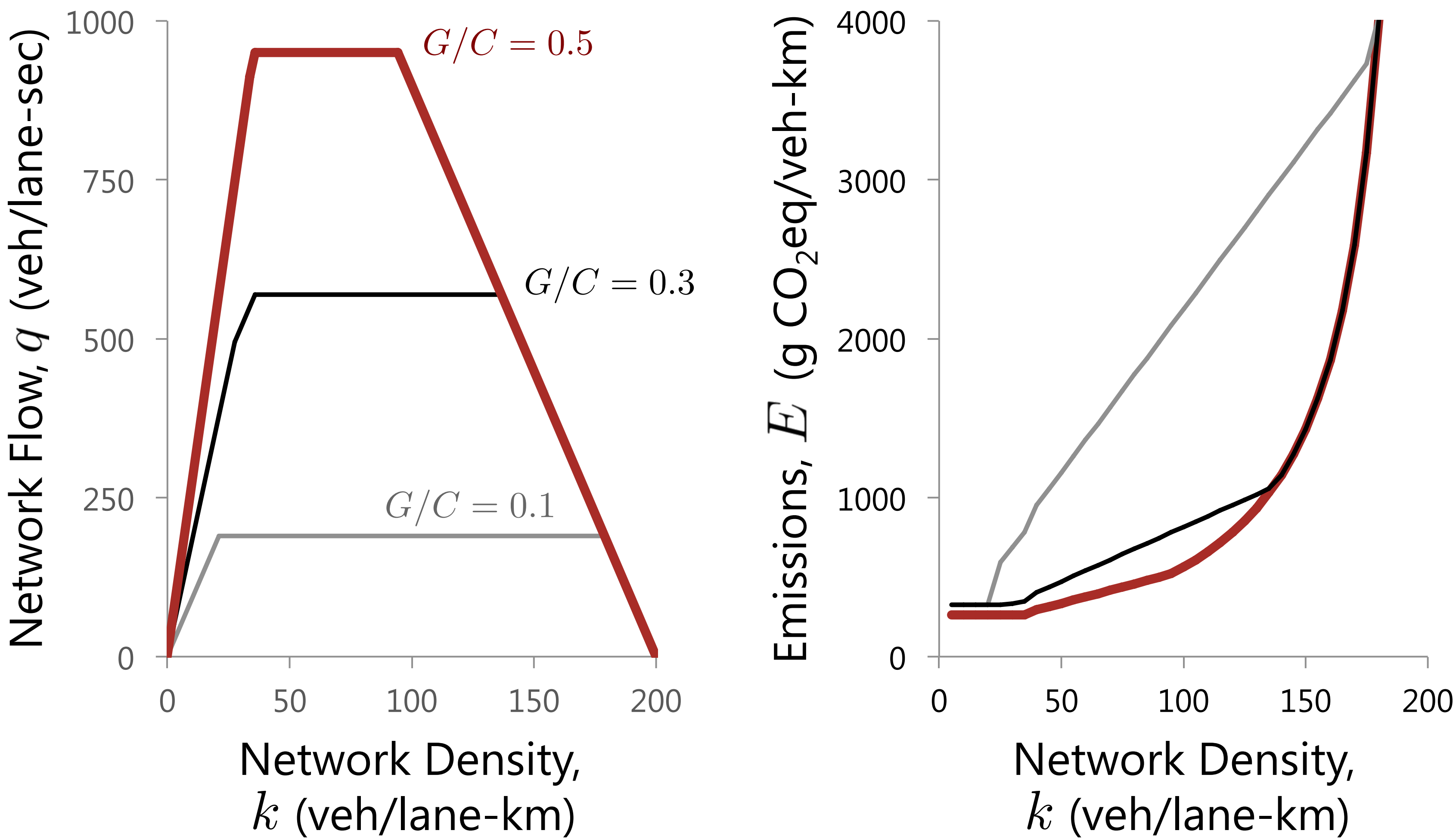
Analytical Model vs. Simulation

Greenhouse Gas Emissions

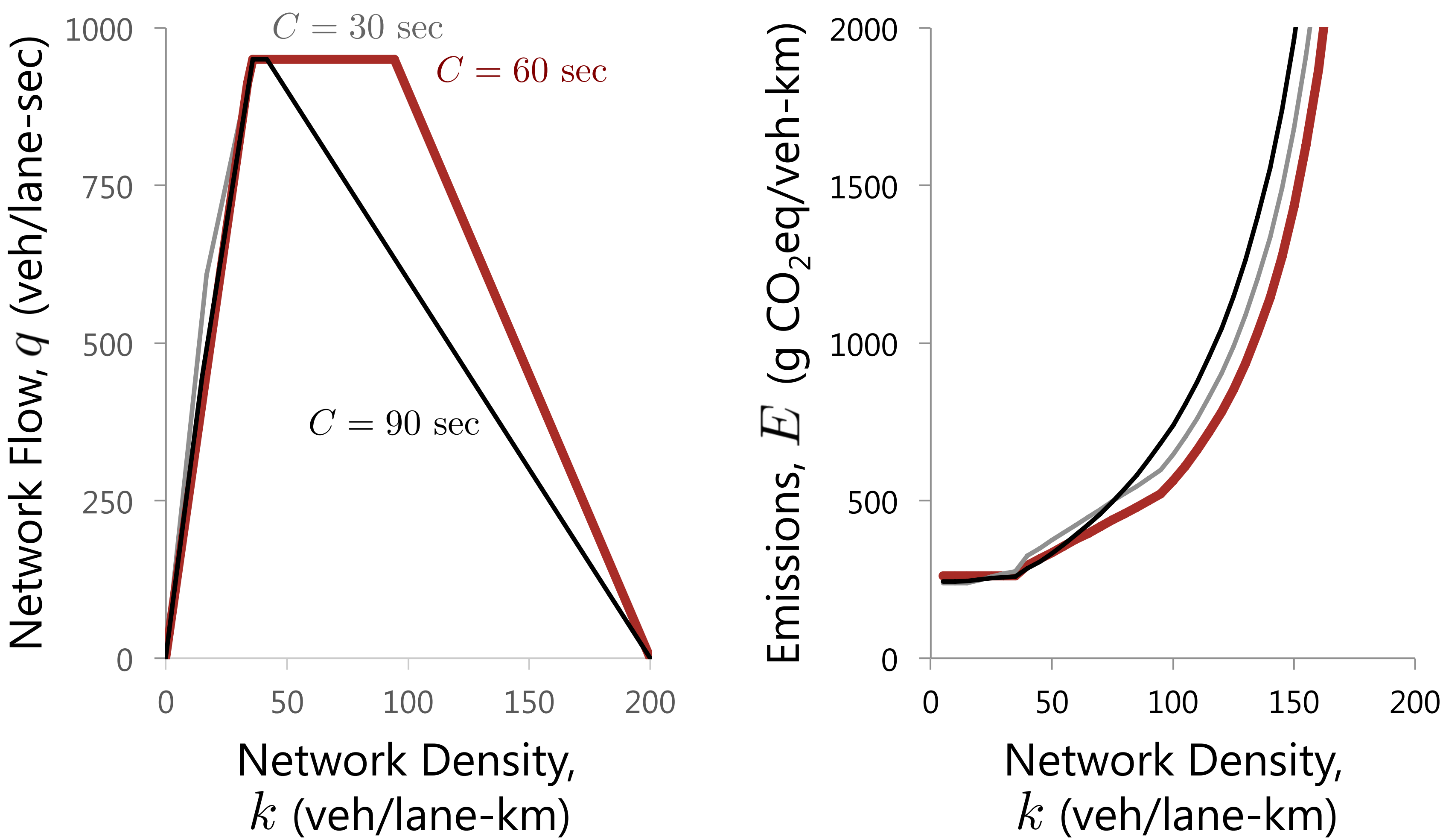


Analytical model estimates the tight lower bound for well-connected, homogeneous networks.

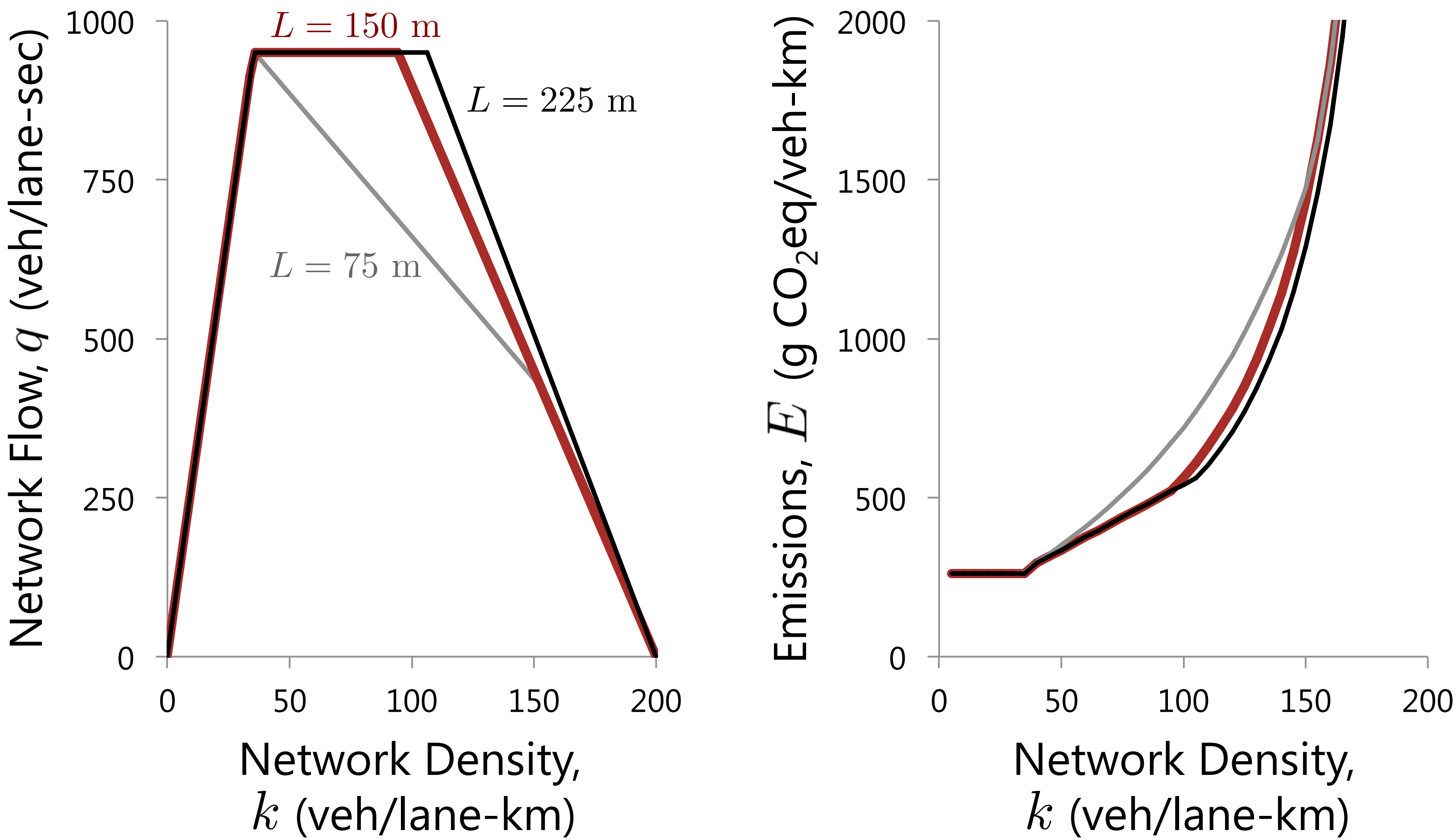
Changing the Green Ratio, G/C



Changing the Signal Cycle Length, C



Changing the Block Length, L



Insights

The MFD embodies useful information for estimating driving cycles without the need for extensive trajectory analysis using conventional microscopic methods. Analytical MFD provides upper bound for flow.

Useful to estimate greenhouse gas emissions, which matter in aggregate, for analysis or monitoring of network traffic. Analytical emission model provides a lower bound for emissions.

Analytical model can account for variations in many network and traffic characteristics (signal timings, block length, etc.).

Current work is to variability of traffic densities across links in a network.

Questions

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